Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Globalstar, Inc. Petition for Notice of Inquiry	)	ET Docket No. 18-___
Regarding the Operation of Outdoor U-NII-1	)	
Devices in the 5 GHz Band	)	

PETITION FOR NOTICE OF INQUIRY

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<u>**Table of Contents**</u>

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	)	
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PETITION FOR NOTICE OF INQUIRY

I. Introduction and Summary

Having recently measured a dramatic rise in the 5.1 GHz noise level, Globalstar, Inc. ("Globalstar") petitions the Federal Communications Commission ("Commission") to issue a Notice of Inquiry regarding the viability of continued spectrum sharing between its licensed Mobile Satellite Services ("MSS") and outdoor Unlicensed National Information Infrastructure ("U-NII") devices operating in the 5150-5250 MHz "U-NII-1" band.[1]

In 2014, the Commission modified its rules to allow the operation of U-NII-1 access points outdoors and at higher power levels than previously permitted.[2] In doing so, the Commission explicitly understood that "Globalstar's licensed mobile satellite service is protected against harmful interference from unlicensed operations."[3] Indeed, NCTA – The Internet & Television Association ("NCTA") then recognized that it is a "fundamental principle

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[1] *Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, First Report and Order, 29 FCC Rcd 4127, ¶ 46 (2014) ("*2014 5 GHz Order*").

[2] *Id.* ¶ 37.

[3] *Id.* ¶ 46.

that unlicensed devices must not cause harmful interference to Globalstar."[4] The Commission further acknowledged Globalstar's technical ability to measure the noise level at its satellite antennas and stated that "should harmful interference to [Globalstar's] licensed services in this band occur," "corrective action" will be required.[5] The Commission also expressed its expectation that parties would notify it regarding any significant development in this band. With this filing, Globalstar formally does so here.

Every Globalstar satellite "hears" all transmissions in the 5096-5250 MHz band across a constantly moving 7,800 kilometer-wide area on the Earth's surface. Aggregate emissions from U-NII-1 access points within this area radiate in the direction of Globalstar's satellites, increasing the noise level in its "feeder uplink"[6] and in turn degrading Globalstar's downlink service to end users. After two plus years of deployments, Globalstar is already experiencing a detrimental impact from outdoor U-NII-1 operations, having confirmed a 2 dB increase in the 5.1 GHz noise level since May 2014, and it will suffer severe harmful interference in the future if the current U-NII-1 "sharing" regime is left unchanged.[7]

The Commission's failure now to take "corrective action" will lead to harmful interference to Globalstar operations not only within the United States, but also in numerous

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4 Letter from Rick Chessen, National Cable & Telecommunications Association, to Julius Knapp, Chief, OET, FCC, ET Docket No. 13-49, at 3 (Jan. 22, 2014) ("NCTA January 22, 2014 Ex Parte").

5 *2014 5 GHz Order* ¶¶ 38, 46.

6 Globalstar's feeder uplinks from its gateway earth stations carry the "forward" traffic from parties communicating with Globalstar MSS handsets from the public switched telephone network, cellular or other wireless networks, or the Internet, depending on the nature of the MSS customer's call and connection.

7 During the prior proceeding, NCTA claimed that "the total additional noise in Globalstar's uplink signal as a result of outdoor, 1 Watt unlicensed operations [would be] approximately 1 dB, even at peak interference levels." NCTA January 22, 2014 Ex Parte at 9-10. As described herein, Globalstar's satellites are already measuring a noise increase that is double NCTA's predicted maximum noise rise.

other North and South American countries, all in violation of the Commission's obligations under the treaty-level ITU Radio Regulation, Resolution 229.[8] Rather than wait until future service disruptions endanger the lives of Globalstar's MSS subscribers and others, the Commission should undertake "corrective action" by expeditiously adopting a Notice of Inquiry seeking public comment on these interference and coexistence issues.[9]

Globalstar reserves the right to petition the Commission for immediate regulatory relief from the harmful effects of unlicensed operations if the noise rise continues on its current course and the detrimental impact becomes severe.

II. Globalstar's Global MSS Network

Globalstar's Satellite Business. In 2013, Globalstar completed the launch of a $1 billion, second-generation non-geostationary ("NGSO") satellite constellation, and it continues to invest in ground infrastructure upgrades and an expanded line of enterprise, consumer, and government products. Globalstar is dedicated to providing state-of-the-art, mission-critical, and safety-of-life services to over 700,000 consumers, businesses, and governmental and public safety users in

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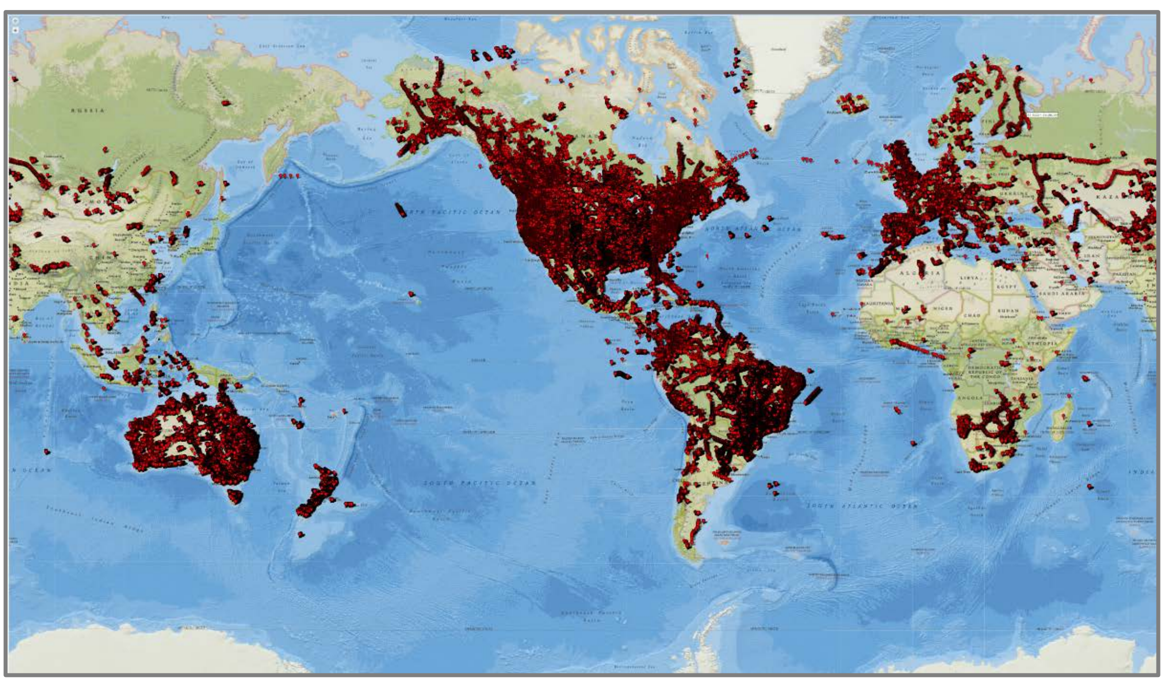
[8] *See* Resolution 229, Volume 3, Radio Regulations – Resolutions and Recommendations at 187, Radiocommunication Sector – International Telecommunication Union (Geneva 2012), http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.41.48.en.103.pdf ("ITU Resolution 229"). The noise rise in Globalstar's uplink spectrum will cause MSS subscriber capacity reductions and degradation of service in the following countries in North America, Central America, South America, and the Caribbean: Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Canada, Cayman Islands, Colombia, Costa Rica, Cuba, Curacao, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Peru, Puerto Rico, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Vincent, Suriname, Trinidad and Tobago, United States, and Venezuela.

[9] In numerous other circumstances, the Commission has released an NOI to develop a robust record before adopting specific rulemaking proposals. *See, e.g., Location-Based Routing for Wireless 911 Calls*, PS Docket No. 18-64, Notice of Inquiry, FCC 18-32, ¶ 5 (rel. Mar. 23, 2018); *Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Notice of Inquiry, 32 FCC Rcd 6373, ¶ 7 (2017); *Revitalization of the AM Radio Service*, First Report and Order, Further Notice of Proposed Rulemaking, and Notice of Inquiry, 30 FCC Rcd 12145, ¶ 81 (2015).

over 120 countries around the world, including remote, unserved, and underserved areas not reached by terrestrial deployments. Globalstar's MSS network provides critical back-up capabilities for public safety personnel during disasters, when terrestrial networks can be rendered inoperable. Public safety entities involved in relief efforts in North America and around the world have relied on Globalstar's satellite services after earthquakes, hurricanes, and other disasters.

Over the past decade, Globalstar has focused on the development of affordable, consumer-oriented devices and services that have significant public safety benefits. This "SPOT" family of MSS devices is responsible for initiating almost 6,000 rescues around the world since the 2007 introduction of this product. Globalstar's subscribers transmitted more than 1.3 billion SPOT and other simplex messages last year, and that figure continues to grow at a significant rate year over year. The map below shows the location and volume of SPOT messages sent around the world during *one day* in September 2017.

SPOT Daily Usage Map – September 2017



With the launch of its second-generation constellation, Globalstar's network now carries increasing duplex (two-way) voice and data traffic. To support its global two-way messaging services, Globalstar has developed an innovative "half-duplex" communications platform that it is currently deploying at its gateway earth stations around the world. As a result of this deployment, all of Globalstar's future products, including the recently introduced "Sat-Fi2" and "SPOT-X" products, will include duplex functionality, relying heavily upon both Globalstar's licensed feeder uplink spectrum at 5 GHz and its licensed 2.4 GHz downlink frequencies.

Globalstar's Gateway Earth Station Infrastructure. Globalstar's satellites currently communicate with 23 gateway earth stations around the world, each serving an area of approximately 700,000 to 1,000,000 square miles. In the United States and its territories, Globalstar currently operates gateway earth stations in Clifton, Texas; Sebring, Florida; Wasilla, Alaska; and Barrio of Las Palmas, Cabo Rojo, Puerto Rico.

Globalstar is authorized for feeder uplink transmissions from its gateway earth stations to its space stations at 5096-5250 MHz and for feeder downlink transmissions between its satellites and its gateway facilities in the 6875-7055 MHz band. Each Globalstar satellite has a feeder uplink antenna that "hears" all transmissions at 5096-5250 MHz – including U-NII-1 Wi-Fi transmissions at 5170-5250 MHz – within the 7,800 km diameter feeder link coverage area. Globalstar's satellites then translate, amplify, and downlink this traffic to its MSS customers at 2483.5-2500 MHz.

Unfortunately, under the 2014 "sharing" framework, aggregate U-NII-1 interference is beginning to diminish Globalstar's MSS subscriber capacity, drain its satellite power, create gaps in its MSS signal coverage, and degrade its service quality in the United States, adjacent areas of Canada and Mexico, Caribbean nations, and Central and South American countries.

III. The Development of the U-NII-1 Band at 5150-5250 MHz and the Commission's *2014 5 GHz Order*

The 1995 World Radiocommunication Conference ("WRC-95") allocated the 5091-5250 MHz band to NGSO MSS feeder uplinks and the 6700-7075 MHz band to NGSO MSS feeder downlinks.[10] In November 1996, the Commission authorized Globalstar to operate its feeder uplinks at 5096-5250 MHz and its feeder downlinks at 6875-7055 MHz.[11]

The following year, the Commission adopted rules making much of this 5.1 GHz band available for use by U-NII-1 devices at 5150-5250 MHz.[12] To protect NGSO MSS feeder links from harmful aggregate interference, the Commission restricted these devices to indoor operations and limited those devices to 50 mW peak output power with up to 6 dBi antenna gain. The Commission stated that "this power limit, along with the restriction on outdoor operations, will provide the desired balance of providing sufficient power for U-NII devices in this band, high frequency reuse, great flexibility in the types of U-NII operations that are accommodated in this band, and protection of co-channel MSS operations."[13]

Globalstar began MSS operations in 2000. For years, Globalstar shared the 5.1 GHz band with unlicensed indoor U-NII-1 devices, representing a fair balance between protecting Globalstar's MSS operations and promoting the development of unlicensed services. In 2013,

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[10] FINAL ACTS of World Radiocommunication Conference 1995 Geneva, at 165-168, ITU, Geneva (1996), http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/4.124.43.en.100.pdf.

[11] *L/Q Licensee, Inc.*, *Application for Modification of License to Construct, Launch, and Operate Low-Earth-Orbit Satellites and Request for Waiver of Table of Allocations*, Order and Authorization, 11 FCC Rcd 16410 (IB-OET 1996).

[12] *Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range*, Report and Order, 12 FCC Rcd 1576 (1997) ("*1997 U-NII Order*").

[13] *Id*. ¶ 44. These U-NII-1 operational and technical rules were virtually the same as those adopted by the ITU in 2003. *See* ITU Resolution 229.

however, just as Globalstar was completing the launch of its second-generation satellite constellation, the Commission released a Notice of Proposed Rulemaking recommending the elimination of the prohibition on outdoor U-NII-1 operations and an increase in the U-NII-1 power limit to levels permitted in other U-NII bands.[14]

Globalstar opposed these revisions and submitted technical analyses from Roberson and Associates, LLC ("Roberson"), which predicted that outdoor U-NII-1 access point transmissions would cause harmful interference to Globalstar's MSS operations throughout North America.[15] As the proceeding moved forward, however, Globalstar worked cooperatively with the Commission's Office of Engineering and Technology ("OET") and industry supporters of the U-NII-1 rule changes – primarily, representatives of NCTA – in an attempt to reach a mutually agreeable solution. In March 2014, Globalstar publicly indicated that it would no longer oppose relaxation of the U-NII-1 technical rules as long as the Commission incorporated certain safeguards into its new framework. Specifically, Globalstar requested that the Commission adopt an antenna downtilt standard limiting outdoor U-NII-1 access points' vertical radiation, as well as a requirement that U-NII-1 operators (i) notify the Commission if they planned to deploy a substantial number of outdoor U-NII-1 access points and (ii) provide the basic technical parameters for those outdoor access points.[16] In addition, Globalstar asked the Commission to

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14 *Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, Notice of Proposed Rulemaking, 28 FCC Rcd 1769, ¶ 40 (2013).

15 *See Impact of Proposed U-NII-1 Rule Changes on Globalstar*, attached to Letter from Regina M. Keeney, Counsel to Globalstar, to Marlene H. Dortch, FCC Secretary, ET Docket No. 13-49 (Nov. 22, 2013); *Progress Report*: *Impact on Proposed U-NII-1 Rule Changes on Globalstar Operations*, attached to Letter from Regina M. Keeney, Counsel to Globalstar, to Marlene H. Dortch, FCC Secretary, ET Docket No. 13-49 (Feb. 7, 2014).

16 *See* Letter from Regina M. Keeney, Counsel to Globalstar, to Marlene H. Dortch, FCC Secretary, ET Docket No. 13-49 (Mar. 6, 2014).

adopt a regulatory "backstop" based on Globalstar's technical ability to measure the noise level at its satellites' antennas. Globalstar argued that, if aggregate harmful interference from outdoor U-NII-1 devices were to rise above a 2 dB threshold, unlicensed users should automatically be required to stop deploying additional outdoor access points and correct this interference, as required under Part 15 of the Commission's rules.[17]

In the *2014 5 GHz Order*, the Commission adopted a subset of Globalstar's proposed safeguards. While the Commission decided to permit outdoor U-NII-1 operations in the United States and raise their power limit, it established an antenna requirement limiting the energy radiated towards space from those devices.[18] According to the Commission, this restriction on upward transmissions would make it "far less likely that harmful interference will occur, even for proliferation of access points greater than that presumed in either party's earlier analysis."[19]

The Commission also adopted a reporting requirement for any entity deploying more than one thousand outdoor U-NII-1 access points in the United States. Such parties must file a letter with the Commission acknowledging that, "should harmful interference to licensed services in this band occur, they will be required to take corrective action."[20] The Commission stated that this corrective action might "*include reducing power, turning off devices, changing*

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17 47 C.F.R. § 15.5(b).

18 Specifically, the Commission's U-NII-1 rules allow fixed outdoor U-NII-1 access points to operate at a maximum conducted output power level not to exceed 1 W and a power spectral density ("PSD") not to exceed 17 dBm/MHz, with a limit of 125 mW EIRP at any elevation angle above 30 degrees from the horizon (allowing for a 6 dBi antenna gain).

19 *2014 5 GHz Order* ¶ 36 ("More specifically, since the noise floor increase seen by the satellite will be a function of the aggregated energy from U-NII-1 emissions at elevation angles above 30 degrees, we can readily address the likelihood of interference to the satellite attributable to this potential increase. Applying technological measures to operations above this elevation angle will sharply reduce the energy that will be received by the satellite from each individual access point, resulting in reduced aggregate noise at the satellite."); *see also* 47 C.F.R. § 15.407(a)(1)(i).

20 *See 2014 5 GHz Order* ¶ 38; 47 C.F.R. § 15.407(j).

frequency bands, and/or further reducing power in the vertical direction."[21] The Commission imposed this reporting requirement to give it the "means to identify readily the largest deployments of U-NII access points, in the unlikely event the number of installations reaches a point where aggregate noise does cause harmful interference to Globalstar and we must take action to avoid such a result."[22] The Commission, however, declined to adopt Globalstar's proposed 2 dB "backstop," reasoning that "the power limits above 30 degrees described above for individual devices, combined with the filing requirements for deployments of large numbers of devices will provide us with sufficient means for avoiding harmful interference and addressing it if it does occur."[23]

Importantly, though, the Commission reaffirmed that Globalstar's licensed MSS operations are protected against harmful interference from unlicensed operations and said that it would continue to monitor developments in the U-NII-1 band. The Commission stated that "should harmful interference to [Globalstar's] licensed services in this band occur," "corrective action" will be required.[24] The Commission acknowledged Globalstar's "capability to monitor increases in noise levels at its satellites, and anticipate[d] that Globalstar will report to us any significant changes in the noise levels and provide specific details as to how it is affecting its

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21 *2014 5 GHz Order* ¶ 38 (emphasis added).

22 *Id.*

23 *Id.*

24 *Id.*

operations."[25] The Commission encouraged all interested parties to continue to communicate regularly with each other and Commission staff regarding developments in the U-NII-1 band.[26]

Despite what appears to be an expansive U-NII-1 roll-out nationwide, only four entities – Comcast Corporation ("Comcast"), Altice USA (previously Cablevision Systems Corporation), Vivint, Inc. ("Vivint"), and Rise Broadband ("Rise") – have filed letters with the Commission to meet their reporting requirements.[27]

IV. Globalstar Has Measured a Significant Increase in the 5.1 GHz Noise Level

Attached as Appendix A to this Petition is Globalstar's report on its satellite measurements.[28] As discussed therein, Globalstar initiated its program to measure the noise level in its feeder uplink spectrum over the United States in May 2014. Globalstar first ascertained the baseline noise floor over the United States at 5096-5250 MHz and calibrated the noise level increases in this band.[29] Thereafter, Globalstar began measuring the noise level as those satellites orbit over the United States. On a monthly basis, Globalstar briefly suppresses communications traffic through its gateway earth station operations in North America in order to allow its satellites to measure the noise level. Globalstar takes these measurements in two-

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25 *Id.* ¶ 46.

26 *Id.* In the months since Globalstar first measured an increased noise level in its feeder link, its representatives have continued to update the Commission and representatives of NCTA and the cable industry regarding the latest developments.

27 *See* Letter from David Don, Comcast Corporation, to OET, FCC (Jan. 15, 2015); Letter from Peter Corea, Cablevision Systems Corporation (now Altice USA), to OET, FCC (2015); Letter from Greg Hansen, Vivint, Inc., to OET, FCC (Sept. 18, 2015); Letter from Damon Estep, Rise Broadband, to OET, FCC (Sept. 28, 2017), https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/u-nii-1-band-515-525-ghz-operator-filing.

28 *Globalstar 5 GHz Noise Floor Measurement Description and Current Results* (May 21, 2018), attached hereto as Appendix A ("Globalstar Measurement Report").

29 *Id*. at 15-18.

minute intervals during daylight hours when satellites are centrally located over the United States and normal daily levels of U-NII-1 Wi-Fi operations are observable.[30]

Globalstar's measurements from May 2014 until February 2017 detected no increase in the noise level. Then, in February 2017, the first satellite measured a 1 dB increase at 5096-5250 MHz.[31] Over the following months, six additional satellites detected a similar 1 dB increase. In March 2017, the first Globalstar satellite measured a 2 dB noise rise. By November 20, 2017, four other satellites had detected a similar 2 dB rise in the noise level. As of April 2018, six of the eight Globalstar satellites involved in this program were measuring a 2 dB noise rise, with the other two satellites measuring a 1 dB noise rise, confirming that the noise level over the United States is now 1 to 2 dB higher than it was when the Commission adopted the *2014 5 GHz Order*.[32]

Globalstar has recently taken additional noise measurements over Europe, Australia and "blue ocean." To date, Globalstar has not detected any noise rise at 5096-5250 MHz over any of these areas.[33] Additionally, Globalstar has conducted nighttime measurements of the noise level over North America.[34] On satellites where Globalstar measured a 2 dB noise rise over the United States during the day, it has detected only a 1 dB noise rise in the middle of the night. This result

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30 *Id*. at 19-20.

31 Globalstar satellites' feeder uplink antenna transponders measure the noise rise in 1 dB increments. As a result, no noise rise was detectable by these satellites until the increase reached at least 1 dB, and no further noise rise above 1 dB was detectable until that increase reached at least 2 dB. All of Globalstar's noise-level measurements have an accuracy of +/- 0.5 dB.

32 Globalstar Measurement Report at 21 and Appendix A. Globalstar provides tables summarizing the results of its noise floor measurements in the Globalstar Measurement Report at A-2 ("Daytime 5 GHz Noise Floor Results Over North America") and A-3 ("5 GHz C/S Noise Floor Summary Timeline (With Measurement Dates)").

33 Globalstar Measurement Report at 21-24, 26.

34 *Id.* at 25.

is consistent with the expectation that reduced human activity during overnight hours results in less Wi-Fi activity, lower access point data traffic, and a lower average access point duty cycle during that time period.

V. The Projected 5.1 GHz Noise Rise Will Have a Severe Detrimental Impact on Globalstar's MSS Operations

Attached as Appendix B to this Petition is a technical report from Roberson ("Roberson Report"), which (i) explains that this noise rise is the result of aggregate emissions from the deployment of outdoor U-NII-1 access points throughout the United States and (ii) describes the substantial detrimental impact that this noise rise will have on Globalstar's provision of MSS to public safety and other customers throughout North America and surrounding areas.[35]

Basic Mechanism for Interference to Globalstar MSS. The increased noise level in Globalstar's feeder uplink band will have a detrimental impact on Globalstar's satellite-to-handset downlink at 2483.5-2500 MHz.[36] Given the "bent-pipe" architecture of Globalstar's satellites, the affected feeder uplink signal – consisting of the desired gateway uplink signal plus noise and the U-NII-1 interference – is translated to Globalstar's service downlink at 2483.5-2500 MHz. Because of the noise rise at 5 GHz, this translation process degrades the received signal at the Globalstar handset, diminishes subscriber capacity, drains satellite power, and creates gaps in MSS signal coverage.

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[35] Roberson and Associates, LLC, *Analysis and Impact of Noise Rise in Feeder Uplinks of Globalstar Mobile Satellite Network* (May 2018), attached hereto as Appendix B ("Roberson Report"). Roberson considered but could find no other potential causes for the noise rise. Roberson Report at 47-52. Aeronautical Airport Communications System ("AeroMACS") facilities are authorized to transmit at 5091-5150 MHz, but there are currently AeroMACS systems operating at only two U.S. airports and such limited operations are incapable of causing a material noise rise. *Id*. at 49. Similarly, federal government Unmanned Aircraft Systems ("UAS") may operate at 5030-5091 MHz, but there are currently only limited test UAS operations in the United States. These transmissions are in any event outside Globalstar's feeder uplink spectrum at 5096-5250 MHz. *Id*. at 48-50.

[36] Roberson Report at 7-9.

Predicting the Noise Rise Due to Outdoor U-NII-1 Operations. The key parameters for the noise calculations in the Roberson Report include the number of outdoor U-NII-1 access points in the United States, the utilization rate or "duty cycle" for these access points, and access point power level and bandwidth.[37] In these calculations, Roberson assumes reasonable outdoor U-NII-1 access point characteristics based on available industry information as well as real-world observations of access point deployments and operations. Roberson also incorporates operating characteristics for Globalstar's MSS network that are consistent with information that Globalstar has previously filed with the Commission. Based on these reasonable parameters and applying a free-space path loss approach that also accounts for a building-shadowing factor, the Roberson Report calculates the aggregate interference power flux density at Globalstar's satellite feeder link antennas, effectively, as of June 2017.[38]

The Roberson Report's quantitative noise floor analysis is consistent with Globalstar's measurements of the noise level over the United States. Roberson's calculations thus provide additional, compelling evidence that Globalstar's measured noise rise is due to the operation of large numbers of outdoor U-NII-1 access points across the United States.

Looking forward, the Roberson Report forecasts a substantial noise rise over the United States, based on (i) industry predictions regarding U.S. access point growth and (ii) reasonable assumptions regarding increased access point utilization due to greater user data consumption. Roberson projects that, compared to the 2014 level, the noise floor over the United States by 2022 would increase by between 4.7 dB and 8.2 dB at 5170-5250 MHz (where U-NII-1 Wi-Fi

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37 *Id.* at 15-32.

38 *Id*. at 25-26, 28-29 (calculating the noise floor rise for different combinations of outdoor U-NII-1 access point populations and average duty cycles, i.e., a combination of one million access points and an average duty cycle of 10% produces a 1.8 dB noise rise at 5170-5250 MHz).

devices operate).[39] Noise floor increases in this range are well above the ITU-R's recommendation for allowable interference to low earth-orbit satellite links and greatly exceed the tolerance level of Globalstar's MSS system. Of course, given that there is currently no U.S. regulatory limit on the number of outdoor U-NII-1 access point deployments, an uncontrolled proliferation could result in the operation of tens of millions of unlicensed U-NII-1 transmitters (by cable providers, other broadband operators, and individual consumers) in the United States and, accordingly, much higher noise rises in Globalstar's *licensed* spectrum.

In addition, while wireless carriers' LTE-U/LAA operations in U-NII-1 spectrum were limited during 2017, these carriers' unlicensed operations have already become much more substantial during 2018.[40] For instance, AT&T is currently serving four markets with LTE-LAA systems (Chicago, Indianapolis, Los Angeles, and San Francisco) and will soon be doing so in Boston, Sacramento, and McAllen, Texas.[41] AT&T plans to deploy 4,000 LTE-LAA sites in 2018-2019, while T-Mobile expects to deploy 25,000 small-cell LTE-LAA sites in the future.[42] While it is not known which U-NII bands are being or will be used for these operations, what percentage of LTE-U/LAA base stations will be deployed outdoors, or at what power level they will operate, these additional unlicensed transmitters at 5 GHz represent a significant concern for Globalstar. If occurring in the U-NII-1 band, carriers' outdoor LTE-U and LAA operations could significantly increase the noise rise in Globalstar's feeder uplink spectrum and the level of aggregate interference to Globalstar's MSS downlink operations at 2.4 GHz. Notably, the Commission likely did not account for the potential emergence of outdoor

[39] *Id*. at 31-32, 54. A noise rise of 4.7 dB to 8.2 dB at 5170-5250 MHz produces a noise rise of 3.0 dB to 5.9 dB across Globalstar's feeder uplink spectrum at 5096-5250 MHz.

[40] *Id.* at 50-52.

[41] *Id*. at 51 n.60.

[42] *Id*. at 51 nn. 62, 63.

LTE-U/LAA operations in the U-NII-1 band at the time of the *2014 GHz Order*, and it appears that the Commission's technical rules for "access points" adopted in that order do not apply specifically to LTE-U/LAA base-station transmitters operating at 5150-5250 MHz.[43]

Substantial Detrimental Impact on Globalstar MSS. The Roberson Report demonstrates that harmful aggregate interference to Globalstar's feeder uplink will have substantial detrimental effects on Globalstar's duplex service downlink to customers in the 2483.5-2500 MHz band.[44] As Globalstar's satellites traverse the United States, a significant portion of their 2.4 GHz coverage area – which includes the United States, adjacent parts of Canada and Mexico, and areas in the Caribbean, Central America, and South America – will at any given moment be negatively affected by aggregate interference from hundreds of thousands of U.S. outdoor U-NII-1 access points. Successive satellites passing over the United States and surrounding areas will experience the same detrimental impact.

Globalstar's network is designed to maintain existing MSS geographic coverage for a given subscriber capacity (number of simultaneous active users). If the noise floor rises between 4.7 dB and 8.2 dB by 2022 (compared to the May 2014 level), Roberson projects that Globalstar's satellite downlink CDMA capacity in affected areas will be reduced by *13% to 35%* during MSS peak hours.[45] If wireless carriers deploy large numbers of outdoor LTE-U/LAA

[43] While OET and the Commission's Wireless Telecommunications Bureau have previously issued a Public Notice seeking comment on a variety of issues related to LTE-U/LAA operations at 5 GHz and elsewhere, it has not adopted any new technical or operational rules specifically applicable to these unlicensed systems. *Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology*, Public Notice, 30 FCC Rcd 4457 (OET-WTB 2015).

[44] Roberson Report at 33-47.

[45] *Id.* at 38-39, 46-47, 54.

base-station transmitters across the United States as expected, Globalstar's subscriber capacity reductions over time will be even more severe.

Another factor reducing MSS subscriber capacity is the effect of the U-NII-1-based noise rise on Globalstar's satellite RF power, which is a finite resource on every satellite.[46] Globalstar satellites' RF power supply will be unavoidably consumed by the amplification and retransmission of undesired U-NII-1 signals received at the satellites' feeder uplink antennas, essentially wasting satellite RF power.[47] This extra expenditure of Globalstar's scarce satellite RF power decreases subscriber capacity and, over time, potentially reduces the lifespan of Globalstar's satellites.

While Globalstar's MSS network generally works to maintain existing geographic coverage, the 5 GHz noise rise will reduce that coverage when the quantity of simultaneous active MSS users in North America is large enough that Globalstar's satellites cannot employ additional power to overcome this interference.[48] In this scenario, a reduced satellite-to-handheld link margin will result in mobile satellite service "holes" in North America and beyond, leading to increased service outages, dropped calls, failed call attempts, and impaired data transmissions. Assuming the anticipated noise rise, Roberson estimates that the geographic availability of Globalstar's MSS offerings in the United States and surrounding areas could be reduced by approximately 365,000 square kilometers by 2022. Within these service "holes," the noise rise would prevent voice calls and data transmissions that otherwise would have been completed successfully.

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46 *Id.* at 39-44, 47.

47 *Id.* at 39-40.

48 *Id.* at 44.

As the Roberson Report describes, the detrimental impact of the noise rise and the resulting loss of subscriber capacity and geographic service availability will be particularly severe during and after natural disasters such as hurricanes, when terrestrial networks are often unavailable and usage of Globalstar's MSS increases substantially.[49] Notably, during Hurricane Katrina, Globalstar's satellite traffic in affected areas occupied up to 78% of Globalstar's CDMA subscriber capacity.[50] When a similar event happens in the future, Globalstar's network may not be able to serve all simultaneous users during such an emergency, when the availability of communications services is a matter of life or death. Globalstar users in this situation would suffer significantly degraded service, including dropped calls, geographic coverage holes, failed call attempts, and impaired data transmissions. In fact, with Globalstar's expanding subscriber base and its introduction of new two-way devices and voice and data services, peak traffic demand on Globalstar's network will be substantially greater during future Katrina-type events.

While the *2014 5 GHz Order* permitted unlicensed outdoor U-NII-1 operations only within the United States, this substantial harm to Globalstar's licensed MSS operations will extend well beyond this country's borders, contrary to the Commission's obligations under the treaty-level ITU Radio Regulation, Resolution 229.[51]

VI. The Commission Is Obligated to Protect Globalstar's Licensed MSS Operations and Its Customers from Harmful Aggregate Interference from Unlicensed Devices

Under the Communications Act, the Commission's rules, and applicable precedent, it is a fundamental duty of the Commission to protect licensed users such as Globalstar from

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[49] *Id.* at 45-46.

[50] *Id*. at 45; *see also* Letter from William F. Adler, Globalstar, to Nancy J. Victory, Chair, Hurricane Katrina Independent Panel, FCC (Mar. 16, 2006) (submitting supplemental information to the Commission pursuant to a request made during Globalstar's presentation made during the Hurricane Katrina Independent Panel's meeting of March 6, 2006).

[51] Roberson Report at 3, 9; *see also* ITU Resolution 229.

harmful interference from unlicensed operations in the United States.[52] Congress tasked the Commission with addressing the problem of interference between competing uses of spectrum, and the Commission's core obligation in this regard is to ensure that unlicensed transmitting devices do not cause harmful interference to licensed operations.[53]

In accordance with the Commission's fundamental duty, Section 301 of the Communications Act requires that "[n]o person shall use or operate any apparatus for the transmission of energy or communications or signals by radio . . . except under and in accordance with this Act and with a license in that behalf granted under the provisions of this Act."[54] The Commission has interpreted this prohibition as inapplicable to unlicensed devices only to the extent that they do not cause harmful interference to licensed operators.[55] That is, the Commission's ability under Section 301 to allow unlicensed U-NII-1 devices to operate is predicated on those devices not causing harmful interference to Globalstar. In addition, Section 302a grants the Commission authority, "consistent with the public interest, convenience, and necessity, [to] make reasonable regulations . . . governing the interference potential of devices which in their operation are capable of emitting radio frequency energy by radiation, conduction, or other means in sufficient degree to cause harmful interference to radio communications."[56] Thus, any Commission rules for unlicensed devices operating in the United States must address the potential of such devices to cause harmful interference to licensed uses.

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52 *See, e.g.*, 47 U.S.C. § 301; 47 C.F.R. § 15.5(b)-(c).

53 *See, e.g.*, *FCC v. Sanders Bros. Radio Station*, 309 U.S. 470, 474 (1940).

54 47 U.S.C. § 301.

55 *See Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, Second Report and Order and Second Memorandum Opinion and Order, 19 FCC Rcd 24558, ¶ 68 (2004).

56 47 U.S.C. § 302a.

The Commission's Part 15 rules for unlicensed operations reflect this fundamental obligation. Specifically, Section 15.5(b) of the Commission's rules requires that operators of unlicensed equipment (i) operate their unlicensed devices on a non-interference basis with respect to licensed services, (ii) accept harmful interference from licensed (as well as unlicensed) facilities, and (iii) in the event of harmful interference to licensed services, either immediately correct the interference problem or terminate unlicensed operations.[57] Part 15 defines "harmful interference" as "[a]ny emission, radiation or induction that endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunications service."[58] The Commission has found that such harmful interference may include interference that diminishes the capacity of a communications system.[59]

As described in Section III, the Commission in the *2014 5 GHz Order* recognized Globalstar's right to be protected against harmful interference from unlicensed operations in the U-NII-1 band.[60] The premise of the Commission's limitations and reporting requirements in that order was Globalstar's continued ability to operate its licensed facilities to the full extent

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57 47 C.F.R. 15.5(b)-(c).

58 47 C.F.R. § 15.3(m). *See also* 47 C.F.R. § 15.1(a) (providing that Part 15 sets out the regulations under which an intentional, unintentional, or incidental radiator may be operated without an individual license); 47 C.F.R. § 15.1(b) (requiring operation of an intentional or unintentional radiator in conformity with the regulations of Part 15 or be otherwise licensed or exempted).

59 *See, e.g.*, *Amendment of Part 25 of the Commission's Rules to Establish Rules and Policies Pertaining to the Second Processing Round of the Non-Voice, Non-Geostationary Mobile Satellite Service*, Report and Order, 13 FCC Rcd 9111, ¶ 53 (1997); *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems,* Memorandum Opinion and Order and Further Notice of Proposed Rulemaking, 18 FCC Rcd 3857, ¶ 76 (2003) ("In cellular CDMA systems, it is a well known fact that cell coverage, capacity and noise are closely related to one another. . . . [A]ny increase in the background noise level will have an impact on both cell coverage and capacity.").

60 *2014 5 GHz Order* ¶ 46.

permitted under its MSS authorizations and applicable Commission rules. If "harmful interference to [Globalstar's] licensed services" occurs, "corrective action" will be required.[61]

The D.C. Circuit has long acknowledged that "the Act does definitely recognize the *rights* of license holders."[62] This right has further been described as a "vested interest [that] must be given due weight in any consideration of fundamental fairness."[63] Indeed, the Commission has recognized "the public interest requires that a Commission license carry with it some reasonable expectation that it will permit the holder to implement its system. Otherwise applicants and licensees – as well as their investors and potential customers – may be unwilling to commit the significant resources necessary to implement proposed systems, and this will have a chilling effect on the introduction of new services to the public."[64]

Here, the proliferation of outdoor U-NII-1 access points throughout the United States will jeopardize Globalstar's operational integrity, the future growth and development of its MSS business, and the interests of first responders, public safety users, rural consumers, and other MSS customers.[65] The Commission should bear in mind that Globalstar invested over $1

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[61] *Id.* ¶ 38.

[62] *Yankee Network, Inc. v. FCC*, 107 F.2d 212, 216 (D.C. Cir. 1939) (emphasis in original). The court in that case found that "the granting of a license by the Commission creates a highly valuable property right, which, while limited in character, nevertheless provides the basis upon which large investments of capital are made and large commercial enterprises are conducted." *Id*. at 217.

[63] *Reuters, Ltd. v. FCC*, 781 F.2d 946, 950 n.5 (D.C. Cir. 1986). *See also Request by Progeny LMS, LLC for Waiver of Certain Multilateration Location and Monitoring Service Rules*, Order, 28 FCC Rcd 8555, ¶ 8 (2013) (in contrast to licensed operators, "parties operating Part 15 devices have no vested or recognizable right to continued use of any given frequency by virtue of prior registration or certification of equipment").

[64] *Establishing Rules and Policies for the Use of Spectrum for Mobile Satellite Service in the Upper and Lower L-band*, Notice of Proposed Rulemaking, 11 FCC Rcd 11675, ¶ 14 (1996).

[65] The Commission has repeatedly acknowledged the threat of harmful aggregate interference from terrestrial wireless operations to licensed satellite services. For example, in May 2013, the Wireless Telecommunications and International Bureaus and OET jointly denied

billion in its second-generation MSS constellation and ground infrastructure in reliance on its effective use of the 5096-5250 MHz band for feeder uplink transmissions, among other things. During that period, Globalstar sought and received various regulatory approvals from the Commission.[66] At no time during this process did the Commission or any other party raise any issues relating to Globalstar's essential use of the 5096-5250 MHz band for its feeder uplink transmissions. Thus, Globalstar reasonably expected that it would be able to use this band for its feeder uplink operations, as it is licensed to do. If the Commission does not address harmful aggregate interference from U.S. outdoor U-NII-1 devices, this inaction will inequitably undercut both Globalstar's investment and the extraordinary public interest benefits generated by its satellite offerings. In addition, other potential providers of new, innovative

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the United Telecom Council and Winchester Cator, LLC ("UTC-Winchester") petition for a new secondary Fixed Service in the 14.0-14.5 GHz band allocated on a primary basis to Fixed Satellite Service ("FSS") uplinks. In rejecting this request, Commission staff noted that the level of harmful interference to FSS uplinks in the 14.0-14.5 GHz band "strictly depends on the aggregate interference power and the receiver performance of the FSS satellite in orbit." *Utilities Telecom Council and Winchester Cator, LLC; Petition for Rulemaking to Establish Rules Governing Critical Infrastructure Industry Fixed Service Operations in the 14.0-14.5 GHz Band*, Order, 28 FCC Rcd 7051, ¶ 6 (OET-WTB 2013). The staff further stated that the "potentially large number of deployments that would be likely under the UTC-Winchester Petition increases the likelihood that a particular station could cause harmful interference to satellite uplinks that are operating on a primary basis in the band." *Id*. ¶ 8. In 2014, the Commission pointed to the threat of harmful aggregate interference from mobile devices in the AWS-3 band to federal satellite operations at 1.7 GHz, and indicated that it would revisit its AWS-3 technical rules in the event harmful interference to those satellite systems was demonstrated. *Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Report and Order, 29 FCC Rcd 4610, ¶ 92 (2014). More recently, in its July 2017 Notice of Inquiry on mid-band spectrum, the Commission noted that, in considering unlicensed use of the 5.925-6.425 GHz band, it would have to consider the potential threat of aggregate harmful interference from large numbers of unlicensed devices to satellite receivers operating in that band. *Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Notice of Inquiry, 32 FCC Rcd 6373, ¶ 29 (2017).

[66] *See Globalstar Licensee LLC Application for Modification*, Order, 26 FCC Rcd 3948 (IB 2011).

communications services will be reluctant to invest in their network if they lack confidence that the Commission will protect their investment.

VII. The Commission Should Expeditiously Issue a Notice of Inquiry

The Commission should expeditiously issue an NOI on the viability of continued spectrum sharing between Globalstar's licensed MSS operations and outdoor U-NII -1 devices, seeking comment on Globalstar's technical information as well as the extent of outdoor U-NII-1 deployment and solutions to the harmful aggregate interference to Globalstar's MSS.

Deployment of outdoor U-NII-1 devices since 2014 5 GHz Order. In the requested NOI, the Commission should ask for detailed information regarding the deployment of outdoor devices in the U-NII-1 band, including the total number of outdoor U-NII-1 access points deployed in the United States, the percentage of such access points that have been deployed outdoors, and how companies define outdoor deployments. The Commission should seek information regarding the equivalent isotropically radiated power ("EIRP") level, antenna gain pattern, and duty cycle of these access points. In particular, the Commission should inquire whether previously deployed or manufactured outdoor U-NII-1 access points comply with the Commission's 2014 antenna requirement limiting the RF energy transmitted by those devices at elevation angles above thirty degrees.[67]

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[67] *See 2014 5 GHz Order* ¶ 36; 47 C.F.R. § 15.407(a)(1)(i). The Commission has granted waivers permitting a limited number of non-compliant U-NII-1 access points to operate outdoors. Letter Order addressed to Ms. Terri Natoli, *Time Warner Cable Inc.*, from Julius P. Knapp, Chief, OET, 30 FCC Rcd 6266 (OET 2015); Letter Order addressed to Mr. David Don, *Comcast Corporation*, from Julius P. Knapp, Chief, OET, 30 FCC Rcd 6269 (OET 2015); Letter Order addressed to Ms. Terri Natoli, *Time Warner Cable Inc.*, from Julius P. Knapp, Chief, OET, 29 FCC Rcd 10008 (OET 2014); Letter Order addressed to Mr. David Don, *Comcast Corporation*, from Julius P. Knapp, Chief, OET, 29 FCC Rcd 10002 (OET 2014); Letter Order to Ms. Jenny Prime, *Cox Communications, Inc.*, from Julius P. Knapp, Chief, OET, 29 FCC Rcd 10005 (OET 2014).

Through this NOI, the Commission should investigate whether any entity or entities have deployed more than one thousand outdoor U-NII-1 access points in the United States without filing the required notification. While it is possible that only a couple of companies have deployed more than one thousand outdoor U-NII-1 access points, equipment authorization data suggest that other operators have done so without complying with the Commission's notification requirement.[68] The Commission should also investigate the marketing and sale of outdoor U-NII-1 access points to the public by online entities and retail outlets.

Finally, the Commission should seek comment on the future scale of commercial wireless carriers' LTE-U/LAA operations in the U-NII-1 band. As described above, while carriers' LTE-U/LAA operations in the 5 GHz band were limited during 2017, these unlicensed operations have already become much more substantial during 2018.[69] The Commission should ask for comment on which U-NII bands are being and will be used for these operations and what fraction of LTE-U/LAA base stations are likely to be deployed outdoors. The Commission should request comment on the number of LTE-U/LAA base station transmitters that are likely to be deployed in the United States and the expected level of utilization for these systems.

*Options for preventing harmful aggregate interferenc*e. In the NOI, the Commission should seek comment on different options for addressing this threat of harm to Globalstar's satellite business and its public safety customers and other users.

First, the Commission should request comment on the benefits of a new rule prohibiting the operation of outdoor U-NII-1 devices in the United States, similar to what was in place prior

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68 If the Commission determines that any companies have deployed more than one thousand outdoor U-NII-1 access points without submitting the required notification, the Commission should require the immediate termination of those companies' outdoor U-NII-1 operations and take appropriate enforcement action against those parties.

69 Roberson Report at 51.

to the Commission's *2014 5 GHz Order*. To provide meaningful protection to Globalstar and its customers, this prohibition would have to apply not just to outdoor access points, but also to LTE-U/LAA base station transmitters and other future outdoor terrestrial systems in this band. The Commission could ask whether certain exceptions to this prohibition would be appropriate, such as for client and end-user devices and fixed point-to-point access points.[70]

A prohibition on outdoor U-NII-1 devices would not restrict outdoor access point transmissions in the 5 GHz U-NII-2A or U-NII-3 bands (or in the 2.4 GHz band). Almost all Wi-Fi access points installed today can operate not only in the U-NII-1 band, but also in these other U-NII bands. Broadband operators should be able to modify the channelization of their access points through centralized network management. By shifting outdoor access points from U-NII-1 to the U-NII-2A or U-NII-3 band, these operators could preserve their outdoor operations at 5 GHz and continue to generate the benefits that the Commission contemplated in its *2014 5 GHz Order*.[71]

The Commission should also seek comment on a U-NII-1 regulatory framework similar to the approach taken by Innovation, Science, and Economic Development Canada ("ISED") in the context of higher power, outdoor access points operating at 5150-5250 MHz.[72] As in Canada, the Commission could consider limiting authority for outdoor U-NII-1 operations to qualified terrestrial wireless operators that typically enjoy effective control over their networks, rather than permit unlimited outdoor deployments. Wireless operators would have one-year,

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[70] *See, e.g.*, 47 C.F.R. § 15.407(a)(1)(iii), (iv) (governing the operations of fixed point-to-point access points and client devices in the U-NII-1 band).

[71] *2014 5 GHz Order* ¶¶ 5-8, 15.

[72] *See Decision on the Technical and Policy Framework for Radio Local Area Network Devices Operating in the 5150-5250 MHz Frequency Band*, Innovation, Science and Economic Development Canada, SMSE-013-17 (May 2017), https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/SMSE-013-17-decision-5150-eng.pdf/$file/SMSE-013-17-decision-5150-eng.pdf.

non-exclusive nationwide licenses authorizing them to register, deploy, and operate fixed outdoor U-NII-1 devices. This framework would enable the Commission to monitor the development and use of the U-NII-1 band, identify the parties responsible for mitigating interference, and help safeguard Globalstar's satellite operations.

As part of this operator-licensed approach, the Commission should also revisit Globalstar's previously requested regulatory "backstop." For instance, when the noise level has risen above a pre-defined threshold, the Commission would institute a licensing freeze and cease issuing additional one-year outdoor U-NII-1 authorizations to new parties. In this scenario, the Commission could consider extending authorizations held by existing outdoor U-NII-1 licensees to license terms longer than a year, but should require any such operators to take the corrective technical and operational measures necessary to prevent detrimental interference to Globalstar's MSS network.

Finally, the Commission should also seek input from interested parties on other regulatory options for minimizing the threat of harmful aggregate interference to Globalstar's MSS operations, as well as parties' views on any market-based or other private approach for addressing these U-NII-1 spectrum use issues.

VIII. Conclusion

For the reasons described in this Petition, the Commission should expeditiously issue a Notice of Inquiry regarding the viability of continued spectrum sharing between Globalstar's licensed MSS operations and outdoor U-NII-1 devices operating at 5150-5250 MHz. It would be contrary to the Commission's statutory obligations – as well as its international treaty obligations – to not be thorough in its review of such an important issue regarding the threat of harmful aggregate interference to a licensee, especially given critical public safety implications. The

Commission's NOI should seek comment on the technical information and analysis appended to this Petition, investigate the scale of outdoor U-NII-1 deployments since *2014 5 GHz Order*, and explore regulatory options for preventing or minimizing the harm to Globalstar's licensed MSS operations and its public safety and other customers.

Respectfully submitted,

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May 21, 2018

Appendix A

Globalstar 5 GHz Noise Floor Measurement Description and Current Results

May 21, 2018

TABLE OF CONTENTS

TABLE OF FIGURES

Summary

In 2014, the U.S. Federal Communications Commission (FCC) issued a Report and Order (FCC 14-30) allowing unlimited outdoor deployment of unlicensed Wi-Fi access points in the U.S. U-NII-1 band, spectrum which includes Wi-Fi channels in 5170-5250 MHz and overlaps the licensed 5091-5250 MHz feeder uplink of Globalstar's Mobile Satellite Service (MSS) as shown in Figure 1: Globalstar Frequency Plan and U-NII-1 Band Overlap.

Prior to the publication/release of FCC Report & Order 14-30 on April 1, 2014, Globalstar had informed the FCC that a rise of 2.0 dB, or greater, in the 5 GHz Noise Floor could cause substantial damage to the Capacity and Quality of Service (QOS) for the Globalstar Duplex Voice Service. During the FCC's rulemaking proceeding, Globalstar requested that a 2 dB "backstop" be defined such that further outdoor deployment of the U-NII-1 band devices would be restricted once the 2 dB noise rise threshold was reached. Ultimately the FCC declined to set any "backstop" on the 5 GHz Noise Floor, but did reaffirm that Globalstar's licensed MSS operations are protected against harmful interference from unlicensed operations and said that it would continue to monitor developments in the U-NII-1 band. The FCC also acknowledged Globalstar's capability to monitor increases in noise levels at its satellites, and stated its expectation that Globalstar would report any significant changes in these noise levels and provide specific details as to how such changes are affecting its MSS operations.

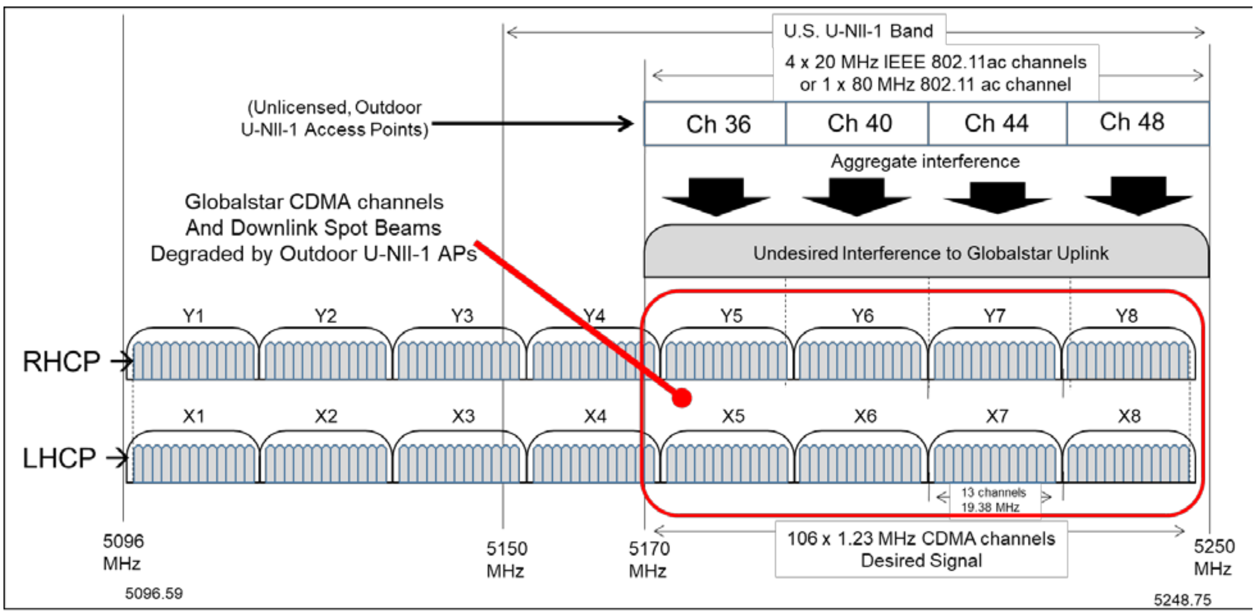


Figure 1: Globalstar Frequency Plan and U-NII-1 Band Overlap

As a result of the FCC's decision to allow the deployment of an unknown number (potentially millions) of U-NII-1 Wi-Fi devices outdoors at higher power, Globalstar decided to initiate a project to characterize, calibrate, and monitor/document the ongoing state of the 5096–5250 MHz frequency spectrum.

The purpose of this White Paper is therefore to describe the Test Methodology utilized to first establish the baseline noise floor within the 5096-5250 MHz band existing in April 2014, and then to measure and track any change in the baseline noise level over time as outdoor deployments of U-NII-1 Wi-Fi devices occurred.

Globalstar has measured and documented a 2.0 dB, +/- 0.5 dB increase from the baseline noise floor within the 5096–5250 MHz band over North America where outdoor, higher power U-NII-1 Wi-Fi deployments have been permitted. Globalstar has not detected any rise in the noise floor over Europe, Australia, or "Blue Ocean," where there have been no similar Wi-Fi deployments.

Globalstar is unaware of any potential cause of the increased noise levels other than the deployment of outdoor, higher power U-NII-1 devices. Further, Globalstar is unaware of any facts or circumstances suggesting that there will not be continued proliferation of outdoor U-NII-1 Wi-Fi deployments in the United States and a concomitant rise in the noise level.

Introduction

The Globalstar 5 GHz Noise Floor Characterization and Monitoring Project is being performed by utilizing existing components and capabilities that were included in the original design of the Globalstar Second Generation Satellite and Ground Systems. The system components described herein are the Satellite Forward Link Transponders and In-Orbit Test System. Although not specifically designed to monitor the noise levels of the satellite transponders, Globalstar is able to periodically configure the system to remove traffic and collect Forward Link Telemetry representing the 5 GHz Noise Floor. This process is further described below.

1.0 Globalstar 5 GHz Characterization and Test System Description

The Project consists of four major components, as listed and described below. These components are:

a. Globalstar Forward Link C-Band Spectrum Utilization Plan
b. Satellite Forward Link Transponder Description
c. Clifton Ground Station IOTE Measurement System Description
d. Long Term 5 GHz Noise Floor Monitoring

1.1 5 GHz Forward Link Spectrum Description

The Globalstar 5 GHz Forward Link Frequency Spectrum, as shown in Figure 2 below, is 5091 MHz to 5250 MHz. The lower 5 MHz of the spectrum is dedicated to the satellite Command Uplink and is not addressed in this White Paper. The upper portion of this spectrum consists of 16 x 16.5 MHz beams. These beams employ frequency reuse, with eight beams on the RHCP polarization and eight beams on the LHCP polarization. As shown in Figure 2, the 16.5 MHz beams are set on 19.38 MHz centers, providing a 2.88 MHz guard band between adjacent beams.

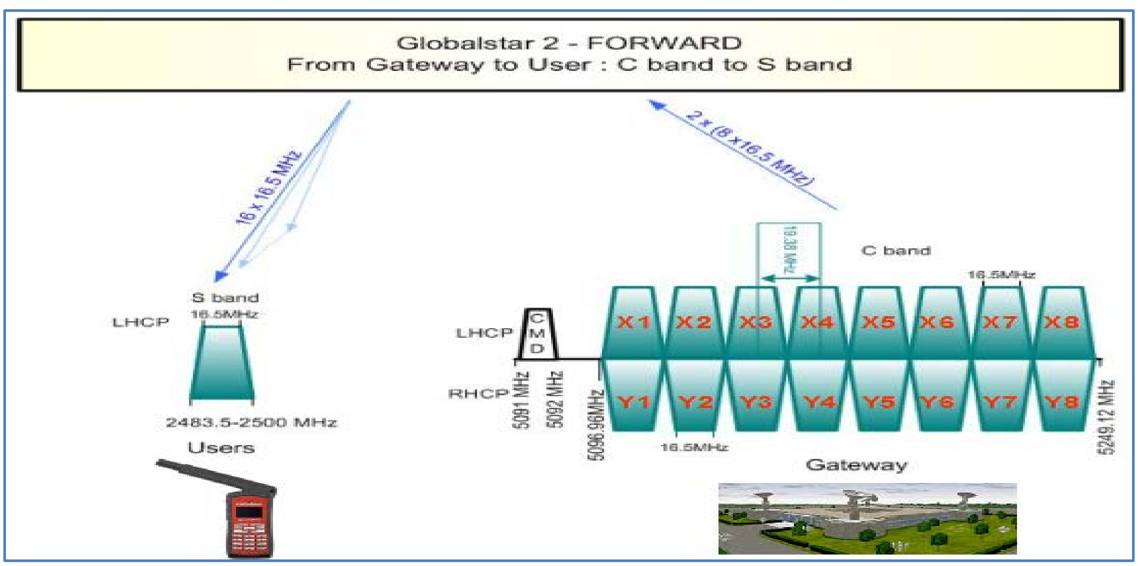


Figure 2: Globalstar Forward Link Frequency Spectrum

1.2 Satellite Forward Link Transponder Description

The Globalstar Second Generation Satellite (GB2) Forward Link Payload, as shown in Figure 3 below, contains 16 individual 5 GHz Transponders which are used to translate the 5 GHz Feeder Uplink from the Ground Gateway to the 2.4 GHz User Downlink. Each transponder is divided into four sections, namely Input LNA Section, Down Converter Section, Power Amplification Section, and Output Section.

The Globalstar Satellites are specifically designed to have "Bent Pipe" Transponders in both the Forward and Return Links. In this case the definition of Bent Pipe is a strictly linear "dB/dB" response in gain across the satellite. This design minimizes any AM/AM distortion that may be generated in the system and provides a stable gain response in support of the CDMA active Power Control Loops running across both the C-S and L-C Transponders. We will discuss this design feature in much more detail in paragraph 1.2.2.4. For the purpose of this White Paper, we are primarily interested in the S-Band Power Amplification section, as it is the location of the noise floor measurements.

1.2.1 C/S Forward Link Transponder - S-band Power Amplifier Section

As shown in Figure 3, the S-band Power Amplification resources in the Payload are made up of 16 active 20 watt power amplifiers, with eight SSPAs dedicated to each polarization (LHCP & RHCP) and with each of these amplifier banks handling eight beams from the 5 GHz C-Band Feeder Link. Additionally, there are Multi-Port Couplers (MPC) located at both the input and output of each S-band power amplifier bank. These MPCs effectively spread the power from each input beam across the eight S-band amplifiers in each polarization.

The MPC design in the S-band Amplifier Section also includes an additional capability, particularly relevant to the Project. The Input Multiport Coupler for each polarization (LHCP & RHCP) spreads the energy of $1/8^{th}$ of the power for each of the eight input beams (5096-5250 MHz) to each of the S-band Power Amplifiers. This summation of beam power enables us to obtain a measurement of the noise floor that is directly representative for all eight beams in each of the RHCP or LHCP polarizations at any one of the RHCP or LHCP S-band amplifier inputs.

Generally speaking, passive components (cables, filters, circulators) and active components (amplifiers, mixers) are subject to non-linear behavior (IM Distortion) when operating at higher signal power levels with an Input Back-off (IBO) of less than 10 dB. However, in the case of Globalstar, during our noise floor measurements, we are operating at approximately 20 dB IBO, in which case the system is operating very linear.

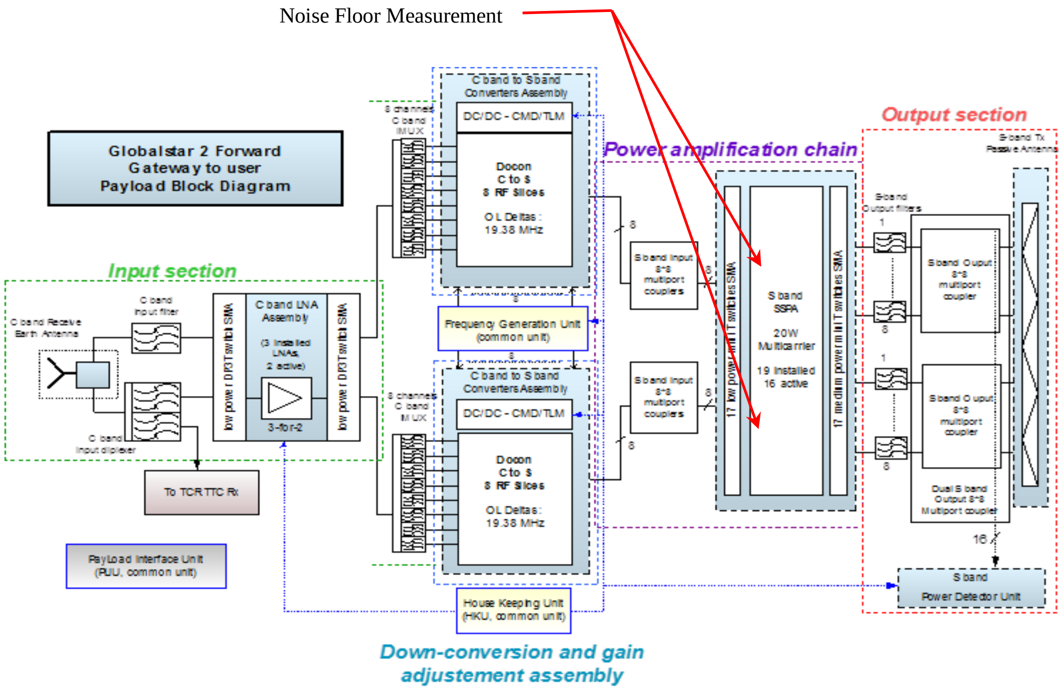


Figure 3: C/S Forward Link Transponder Block Diagram

1.2.2 C/S Transponder Band-Pass Filtering

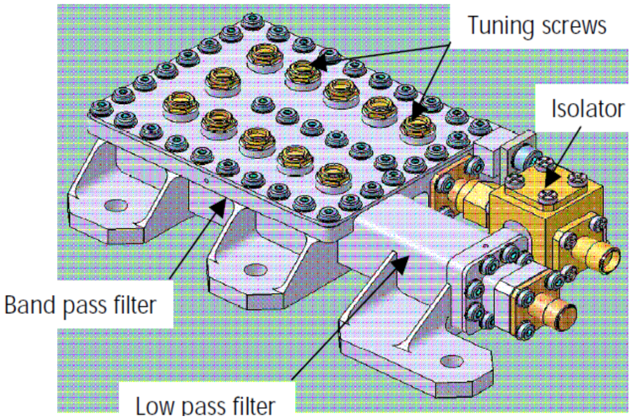
The C/S Forward Link Transponder has significant band pass filtering at six locations along the C/S Forward Link Transponder RF chain. These bandpass filter locations and characteristics are listed below, and shown in Figure 4, Figure 5, and Figure 6.

Bandpass Filter Details and locations:

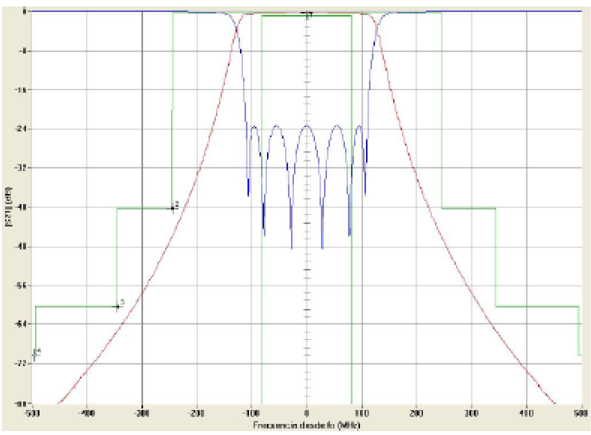
1. C-Band Input Filter
2. C-Band IMUX Beam Filters
3. C/S Down Converter Filtering
    a. C/S Down Converter C-Band Input Filter
    b. X-Band Bandpass Filter on Local Oscillator Mixer Input
    c. C/S Down Converter S-Band Output Filter

1.2.2.1 C-band Input Filter

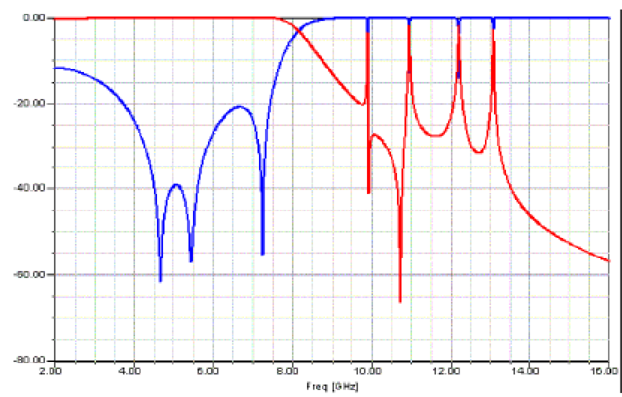
The C-Band Input Filter is installed immediately in front of the C-Band LNA and effectively sets the noise figure performance of the C/S Forward Link Transponders to 550 K (4.62 dB). The C-Band Input Filter consists of a Combline/Reentrant Cavity bandpass filter followed by a low pass filter section. Specific details of the filter performance are shown below in Figure 4.



Parameters		Characteristics
Frequency range		5097 – 5250 MHz
Insertion loss	Level	1 dB
	Flatness	0.05 dBpp over any 16 MHz
	Stability	0.25 dBpp over temperature range and lifetime
	Interfaces for secondary power supply	
Group delay	Flatness	0.2 nspp over any 1.23 MHz, 2ns over any 16 MHz
	Stability	+/- 1 ns over 15°C
Mass		0.155 kg
Dimensions (L x W x H)		120mm x 77mm x 30mm



Combline filter : Selectivity Response



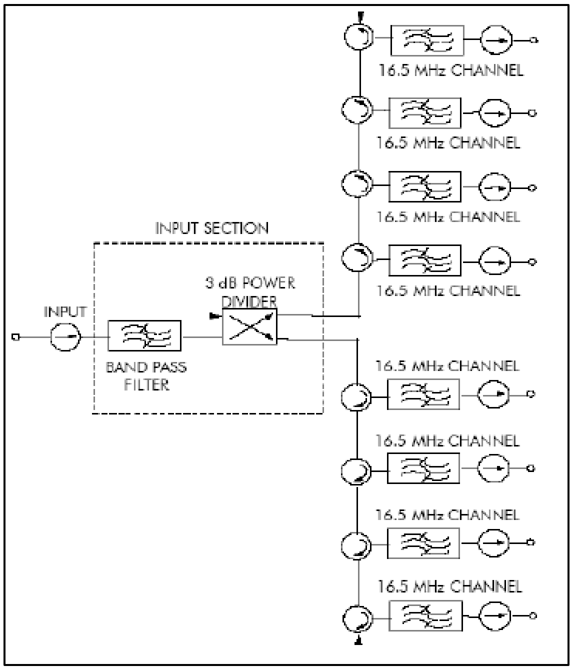
Low pass filter : Transmission and reflection

Figure 4: C-Band Input Filter Characteristics

1.2.2.2 C-Band IMUX Beam Filters

The C-Band IMUX Beam Filters, as shown above in the C/S Forward Link Transponder Block Diagram (Figure 3) are installed immediately following the C-Band LNAs and prior to the C/S Down-Converter assembly. The IMUX Beam Filters are utilized to isolate the eight individual C-Band RHCP and LHCP Beams for conversion to S-Band frequencies as shown in Figure 5 below. Also, as shown in Figure 5 (IMUX Layout), the unit contains, along with the channel filters, an additional stage of bandpass filtering (5096–5250 MHz).

IMUX layout (RHCP &



IMUX Channel Frequency

Channel	Center frequency Fc (MHz)	Channel bandwidth (MHz)
1	5105.21	16.5
2	5124.59	16.5
3	5143.97	16.5
4	5163.35	16.5
5	5182.73	16.5
6	5202.11	16.5
7	5221.49	16.5
8	5240.87	16.5

IMUX Channel 1 Filter

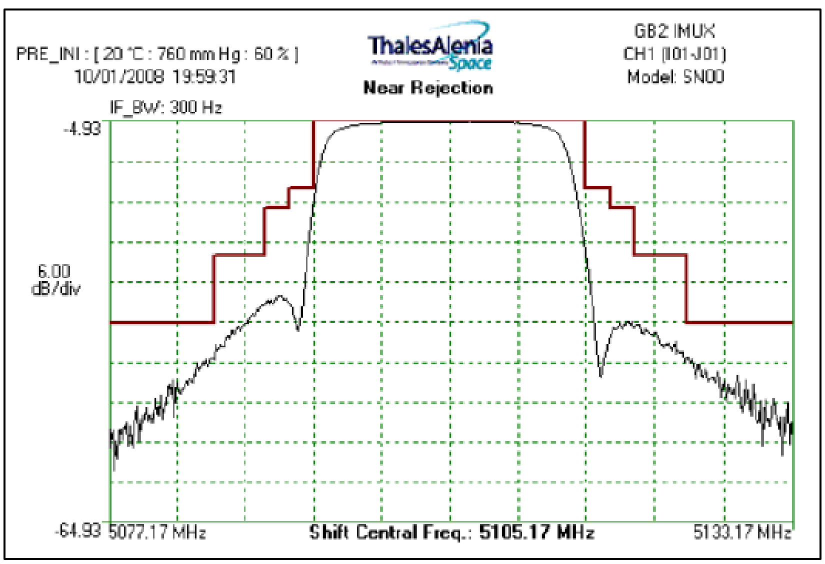


Figure 5: IMUX C-Band Channel Passband Filter Characteristics

1.2.2.3 C / S Down Converter Filtering

The C/S Down Converter assembly is utilized to convert the eight RHCP C-band channels and eight LHCP C-band channels to the S-band frequencies (2483.5–2500 MHz) required for the Globalstar User devices.

The C/S Down Converter, as shown in Figure 6 below, has three types of bandpass filtering implemented internally in the unit. In order to minimize unwanted non-linear behavior in the C/S Mixer the unit has bandpass filtering circuitry surrounding the mixer at three locations: immediately prior to the mixer (C-band), at the L.O. input to the mixer (X-band), and at the S-band output of the mixer (S-band).

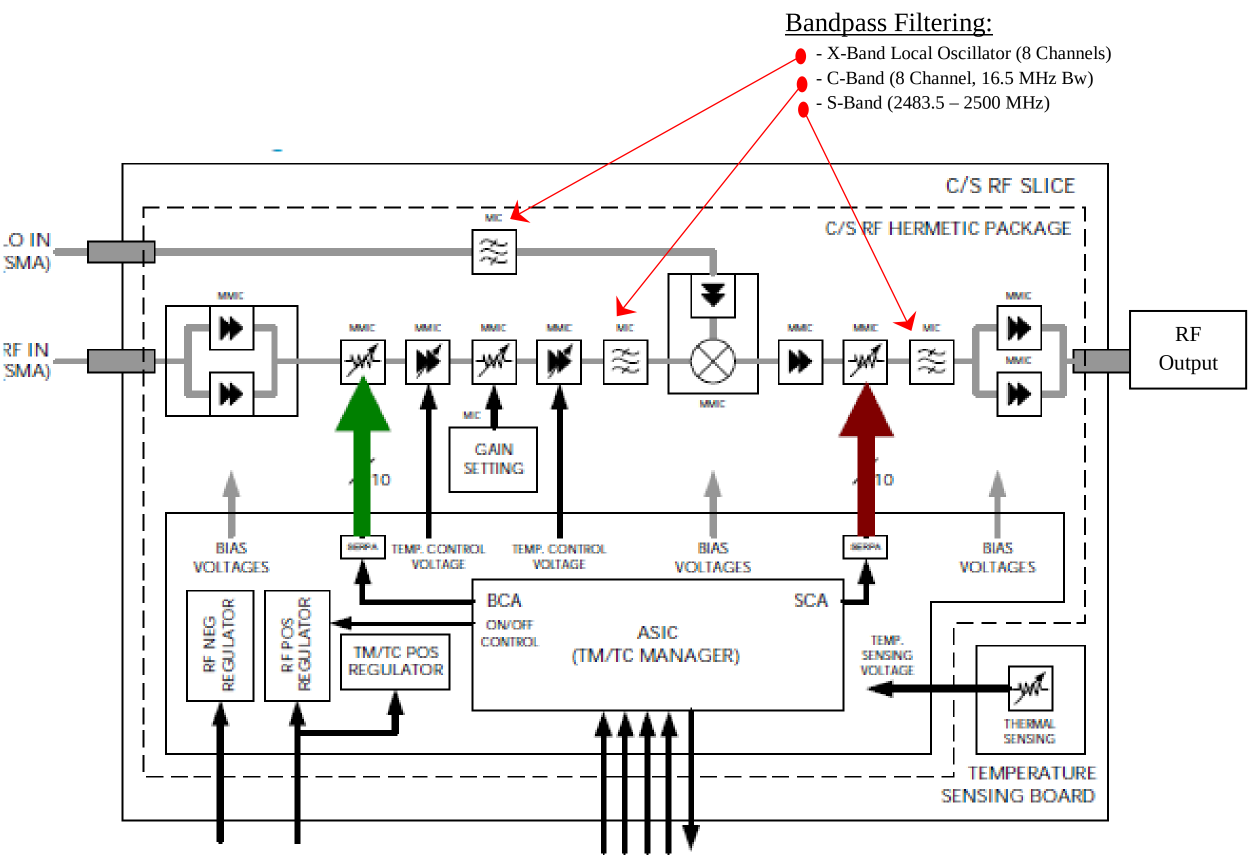


Figure 6: C/S Down Converter Block Diagram

1.2.2.4 Globalstar Second Generation Satellite Gain Transfer Performance

The Globalstar CDMA Duplex Voice processing system is implemented utilizing real-time high rate, active “Power Control” loops between the ground Gateway and Phone Users. These C/S Forward and L/C Return Link Power Control loops are required in order to maintain the excellent duplex voice quality that Globalstar provides its subscribers. One of the primary parameters necessary in operating these power control loops is a stable and linear Gain Transfer Function across the Satellite Space-To-Ground Interface.

Immediately following each of the Globalstar GB2 satellite launches, we conducted an extensive In-Orbit Test (IOTE) program on each of the satellites, consisting of Antenna Patterns, Gain Flatness, Frequency Translation, Group Delay, Filter Bandwidths, Spurious Signal, and Gain Transfer measurements. These measurements were designed to verify that the satellites reached their operational orbits safely and also to establish a baseline set of performance measurements to track any changes that may be occurring during the planned 15+ year lifetime of the Globalstar Second Generation Constellation.

Of special interest in the 5 GHz Noise Floor Monitoring Program is the linear gain performance (dB_{out}/dB_{in}) of the satellite at the noise floor of the SSPA RF Input signal power detector. Although we cannot directly measure just the front end portion of the C/S Forward Link Transponder, we can directly measure the linearity of the entire Transponder with the IOTE Gain Transfer Measurement capability.

Shown below in Figure 7 and Figure 8 are two IOTE Gain Transfer Measurement reports on satellite M092 C/S Beam S03. The first measurement was conducted on March 3, 2012 and indicates that the transponder gain was linear to within < 0.5 dB over a range of ~10 dB input back-off (IB0) down to the noise floor. The second measurement is also a Gain Transfer measurement on satellite M092 C/S Beam S03. This measurement was conducted on March 14, 2018 and also indicates that the transponder performance at the noise floor has remained linear to within < 0.5 dB.

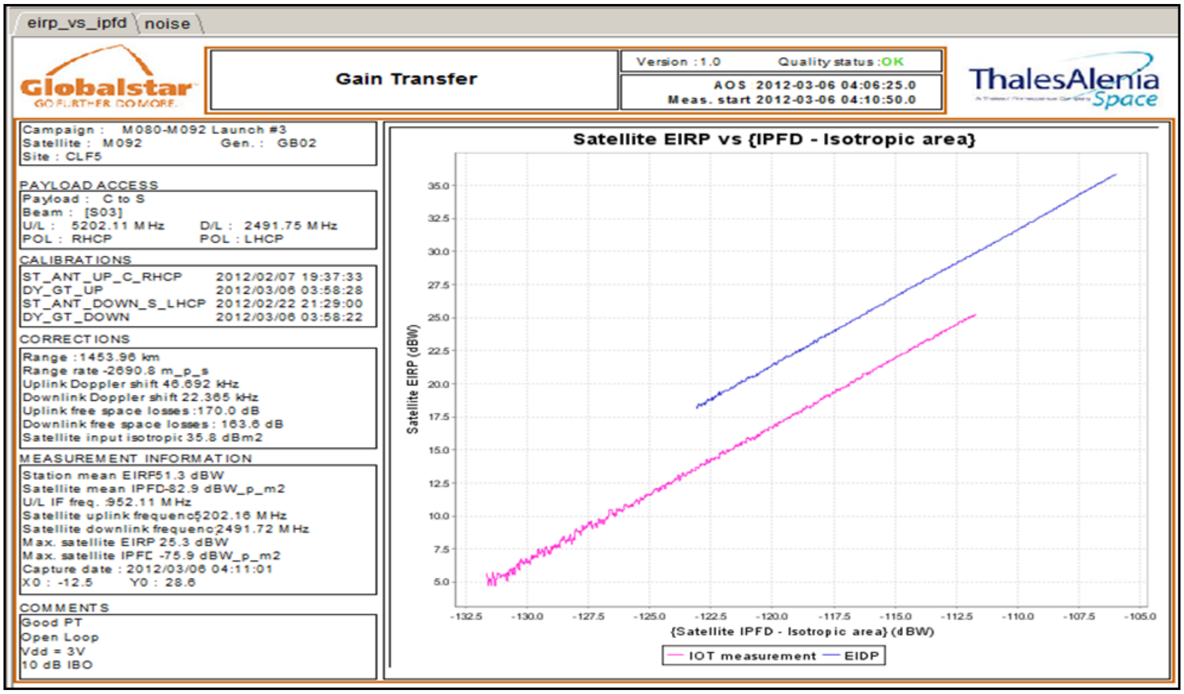


Figure 7: M092 C/S Beam S03 IOTE Gain Transfer Measurement, March 3, 2012

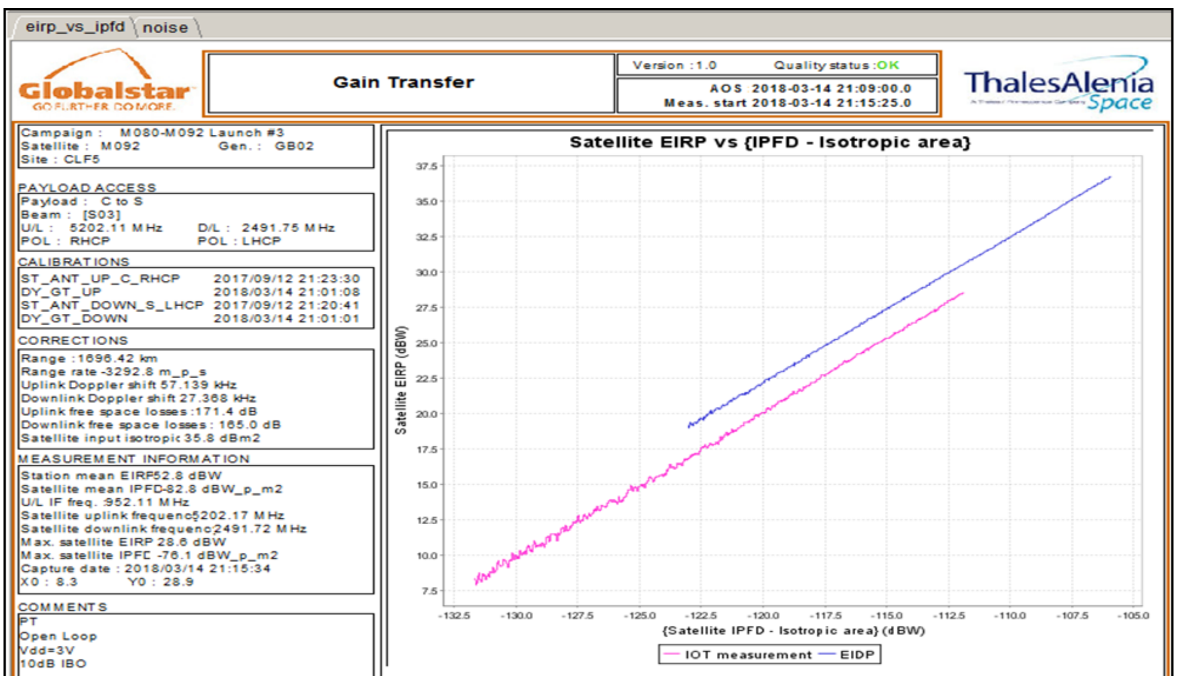


Figure 8: M092 C/S Beam S03 IOTE Gain Transfer Measurement, March 14, 2018

2.0 Clifton Ground Station IOTE System Description

The Globalstar In-Orbit Test System (IOTE), located at the Clifton, TX Globalstar Gateway site, contains the hardware and software required to perform the 5 GHz Noise Floor Characterization testing. The IOTE system was originally designed to perform the initial In-Orbit Testing and Qualification of the GB2 Satellite constellation following the four Globalstar Constellation launches from 2010 through 2013.

In late 2013, during the planning stages of the Project, we determined that we could reconfigure the IOTE system to provide uplink signals that could simulate the interfering signal. The U-NII-1 Wi-Fi simulated signal is generated using an Anritsu MG3700A Arbitrary Waveform Generator/Upconverter (AWG), executing an 802.11ac Waveform file. Figure 9 shown below contains a partial Block Diagram of the Clifton Gateway C-Band Antenna to IOTE Rack Interface signals that were used during the 5 GHz Noise Floor Characterization Testing.

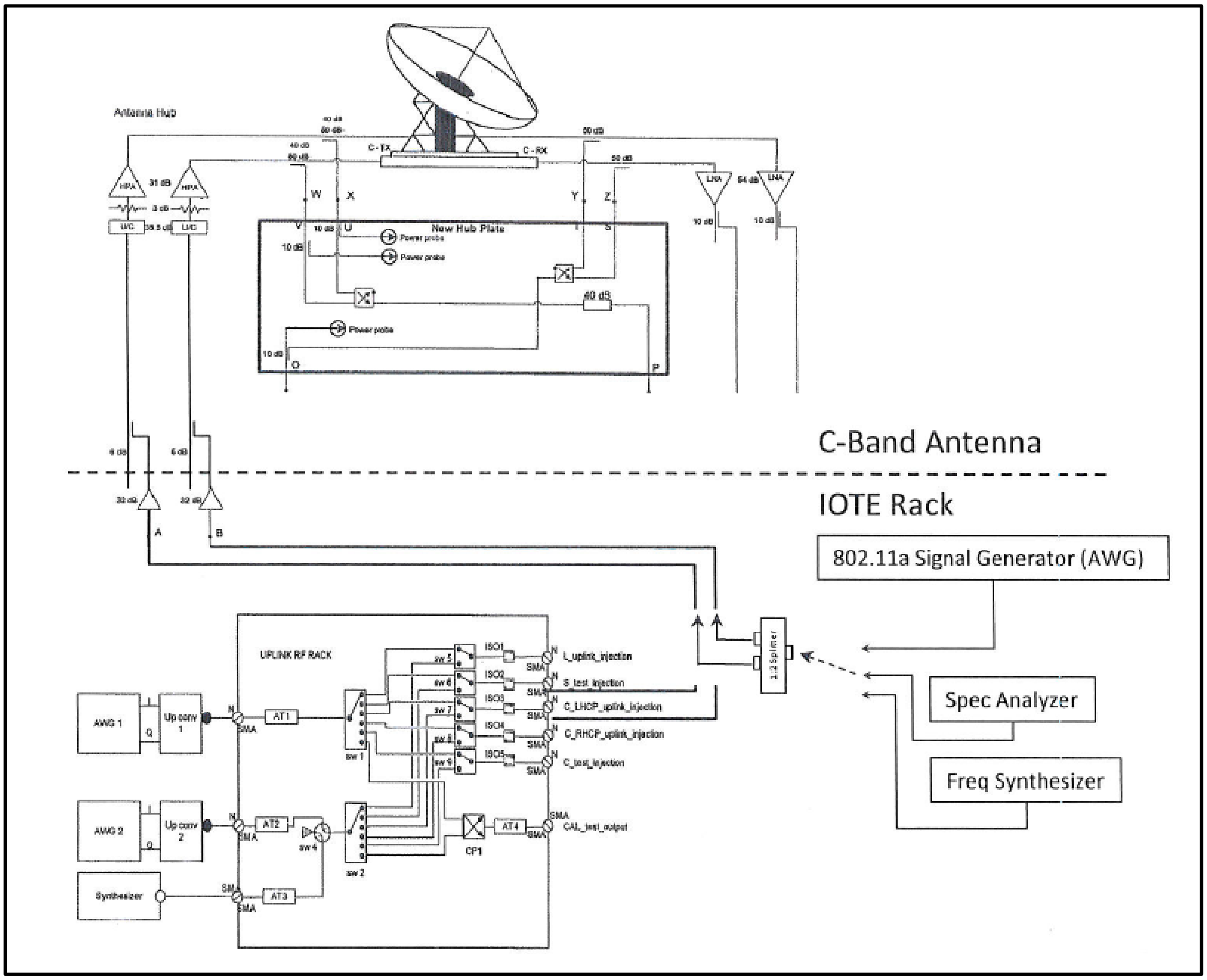


Figure 9: C-Band & IOTE Ground Hardware Block Diagram

3.0 5 GHz Noise Floor Characterization and Monitoring Methodology

The 5 GHz Characterization Testing will consist of three primary tasks.

a. Characterization Test Procedure Development
b. Characterization of the Globalstar Constellation 5 GHz Noise Floor
c. Initiation of the Long Term Monitoring of the Constellation 5 GHz Noise Floor

3.1 Development of the Ground-to-Space Uplink Calibration Procedure

3.1.1 Noise Floor Calibration Measurement Definition

The basic requirement for the calibration procedure was to perform the uplink of the test 802.11ac simulated Wi-Fi signal to the satellite under test at the time when a two minute "No Traffic" outage period has been previously scheduled.

During the outage, the power level of the AWG (simulated 802.11ac) based signal was increased in ½ dB steps (see Figure 8) until the SSPA telemetry from the satellite indicated a rise in the 5 GHz Noise Floor at the input to the SSPAs. In each measurement, the stepping was continued until the noise floor was increased by 3 dB (see Figures 10 & 11). Also, during each calibration test, the C-Band EIRP of the simulated 802.11ac interfering signal was recorded for each ½ dB step of the test. This process allows us to directly equate a measured increase in the level of the 5 GHz Noise Floor, as seen at the satellites to the total Ground C-Band EIRP causing the increase in the satellite 5 GHz Noise Floor. This approach established the baseline noise floor level with an accuracy of +/- 0.5 dB, meaning that subsequent noise-rise measurements over North America have an accuracy of +/- 0.5 dB.

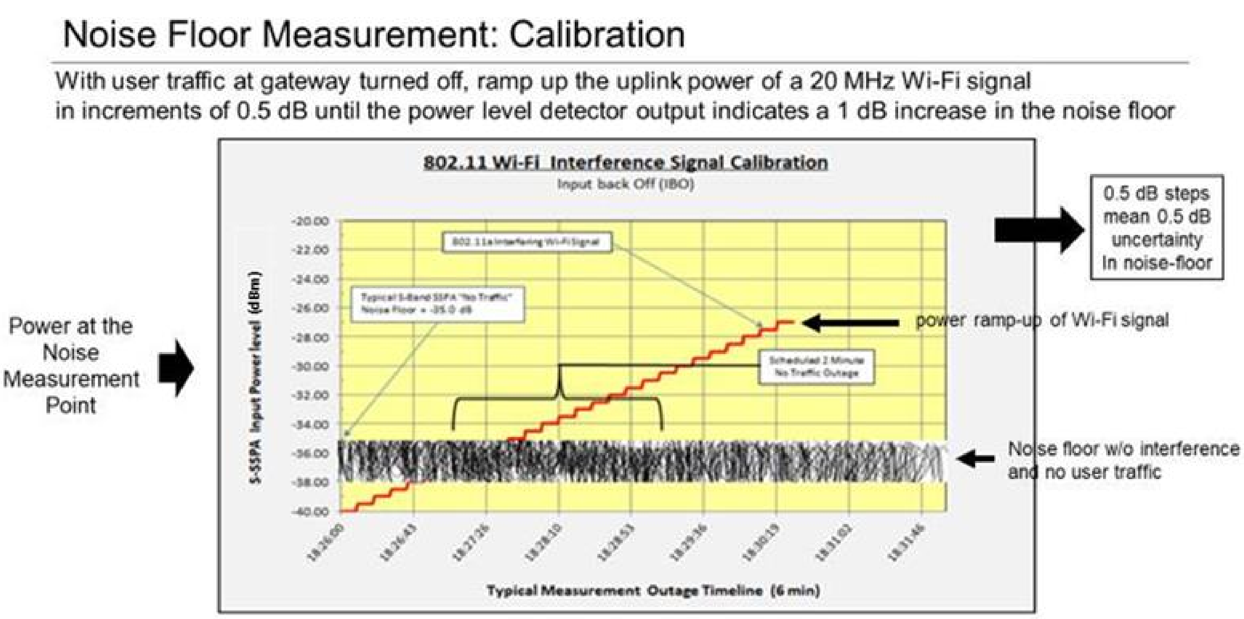


Figure 10: 5 GHz Noise Floor Interfering Signal Calibration

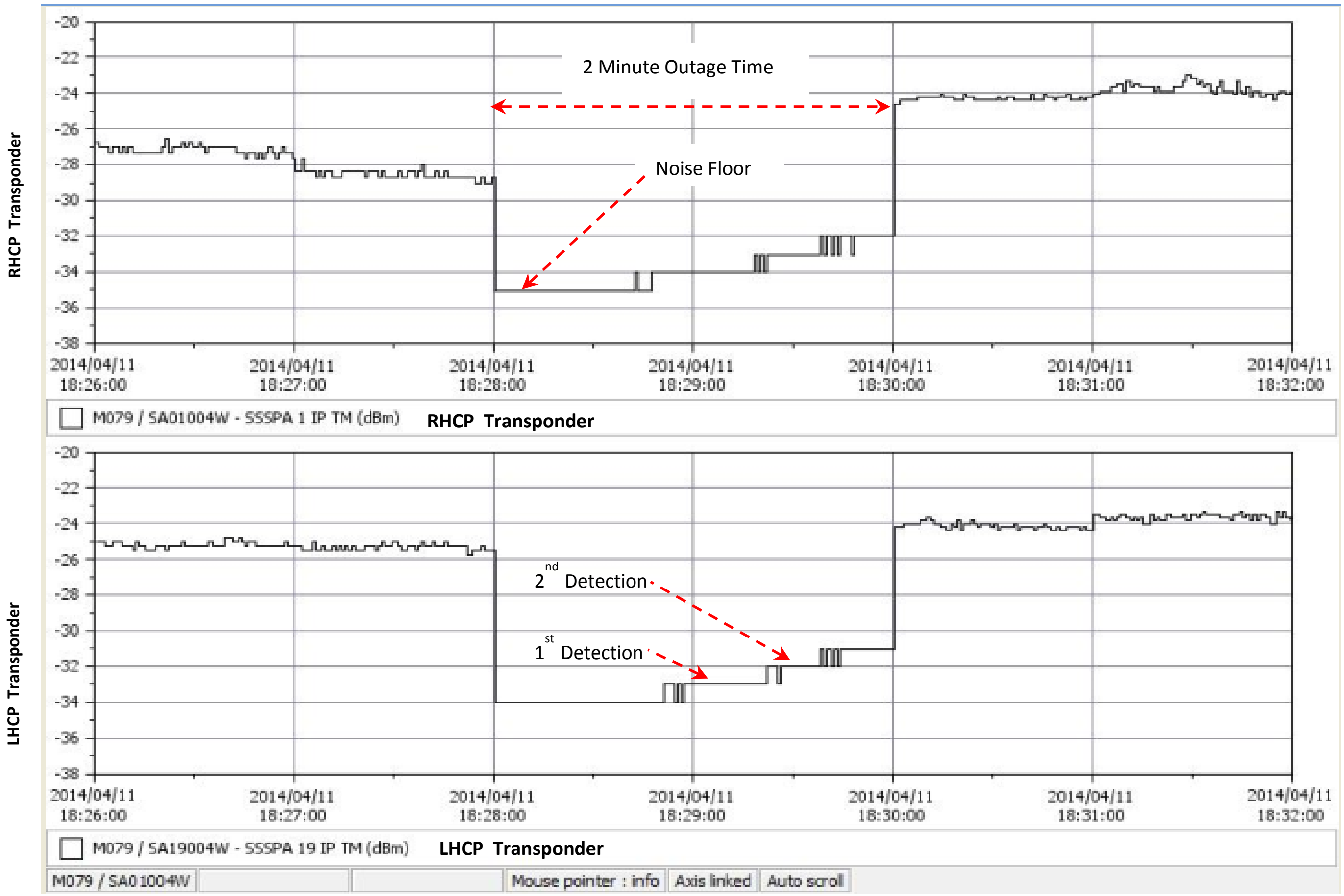


Figure 11: M079 Noise Floor Calibration Test Example (April 11, 2014)

3.1.2 5 GHz Noise Floor Measurement Telemetry Interpretation

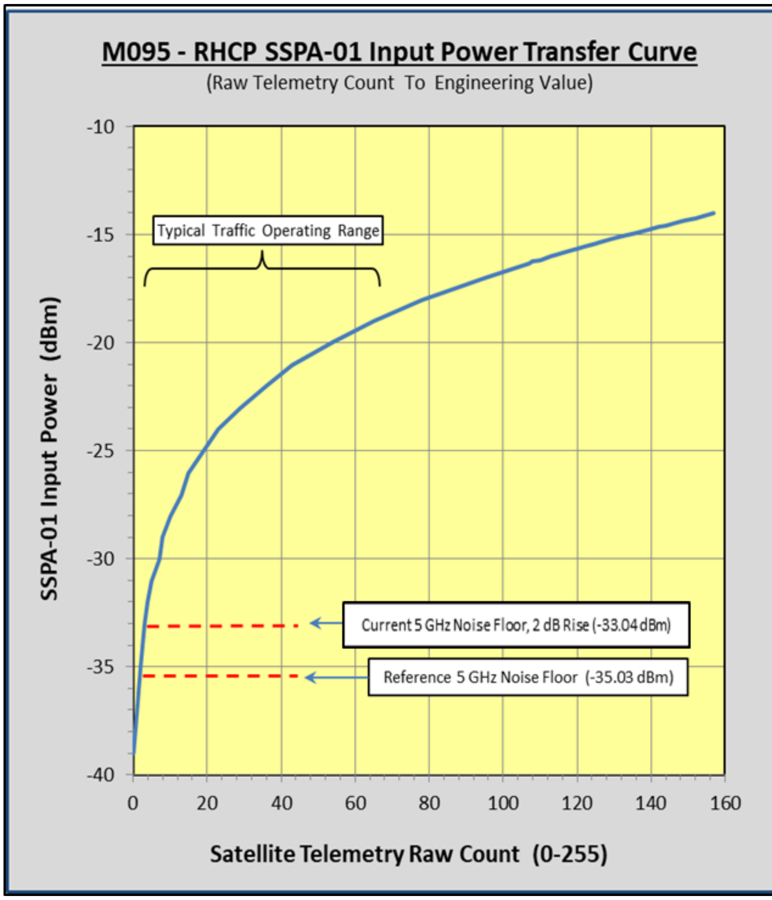
The S-Band SSPA Input Power telemetry that is used to measure the 5 GHz Noise Floor is collected on board the satellite using a "Sample & Hold Peak Detector" which is widely used to convert signals from analog to digital representation. In the case of the S-Band SSPA Telemetry used for our testing, the analog signal is A/D converted into an 8 bit digital Word (0-255) representing SSPA Input Power in dBm at the instant of the measurement.

The SSPA Digital Raw Data is then sent to the ground along with all of the other satellite subsystem data items in the satellite telemetry downlink stream. Once on the ground, utilizing a Transfer Curve like the one shown in Figure 12, the digital data "raw count" is converted back into an analog representation of the SSPA Input Power Level in dBm.

In practice, the interpretation of the noise rise measurements will be limited to values in dBm listed in the associated Telemetry Transfer file (TTF). For example, this means that a satellite that is currently indicating a 0 dB noise rise will continue indicating 0 dB until the interference signal rises to a level which exceeds the next entry in the TTF. At that time, the measurement will indicate a 1 dB, +/- 0.5 dB rise in the 5 GHz noise floor.

Subsequently, a satellite that is currently indicating a 1 dB noise rise will continue indicating 1 dB until the interference signal rises to a level which exceeds the next entry in the TTF, signaling a 2 dB, +/- 0.5 dB noise rise. Similarly, a satellite that is currently indicating a 2 dB noise rise will continue indicating 2 dB until the interference signal rises to a level which exceeds the next entry in the TTF, signaling a 3 dB, +/- 0.5 dB noise rise.

Normally, the SSPA Input Power level is sampled at 32 second intervals. Recently, the sample rate was increased to provide samples at eight second intervals to provide increased time resolution of the measurement. During the time when the interfering signal is increasing from one quantization level to the next quantization Level (1.0 → 2.0 dB), we sometimes see the measurement toggle between the two levels during the two minute measurement period.



SSPA-01 Input Power Transfer Data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Description="FM23 S-BAND SSPA 6SA1-01 RF INPUT POWER
Ambient phase Transfer function">
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<TF_Point RawValue="159" PhysicalValue="-13.96" />
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<TF_Point RawValue="255" PhysicalValue="-7.240000" />
```


Figure 12: S-Band SSPA Telemetry Transfer Curve Definition

3.2 5 GHz Noise Floor Measurement Database Establishment

When we had completed the development of the Calibration Procedure, we performed a noise floor survey of eight of the satellites in the Globalstar Second-Generation Constellation. The eight satellites chosen included one each from the eight Orbital Planes in the Globalstar Constellation. The survey consisted of performing at least five measurements on each of the C/S forward Link Transponders in the Globalstar Constellation. During each measurement, the following data was collected.

a. RHCP – Baseline "No Traffic" noise level
b. RHCP – Power level of "first detection" (1.0 dB Rise) of a Wi-Fi interfering signal
c. RHCP – Power level of "second detection" (2.0 dB Rise) of a Wi-Fi interfering signal
d. LHCP – Baseline No Traffic noise level
e. LHCP – Power level of first detection (1.0 dB Rise) of a Wi-Fi interfering signal
f. LCHP – Power level of second detection (2.0 dB Rise) of a Wi-Fi interfering signal

During the tests, the Globalstar Satellite Operations Control Center (SOCC) collected the S-Band SSPA Input Power Telemetry, which constituted the satellite response for each test. Also collected during the tests were the complete sequences of ground test equipment power level settings versus test time. These uplink power level settings permit an analysis of the amount of Wi-Fi ground EIRP versus the interfering Wi-Fi signal level received at the satellites, as shown in Figure 13.

RHCP Noise Floor Reference Data

Sat ID	Reference Noise Floor (dBm)	1st (1 dB) Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	Calibration Elev Angle (deg)	2nd (2dB) Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	Calibration Elev Angle (deg)
M079	-35.04	-34.05	41.88	44	-33.04	45.11	46
M082	-34.98	-34.02	40.83	43	-33.04	44.32	47
M083	-35.02	-33.99	42.26	41	-33.01	44.72	44
M089	-35.02	-34.03	40.27	50	-33.01	44.3	56
M092	-34.98	-34.03	39.75	46	-32.97	42.15	47
M095[1]	-35.03	-33.04	40.52	42	-31.99	45.33	46
M096	-35.03	-33.96	39.49	57	-33.01	43.37	60
M097[1]	-35.01	-33.02	41.60	53	-32.01	44.96	56

1. 1st detection resolution on M095-R and M097-R is 2 dB noise rise.

LHCP Noise Floor Reference Data

Sat ID	Reference Noise Floor (dBm)	1st (1 dB) Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	Calibration Elev Angle (deg)	2nd (2dB) Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	Calibration User Angle (deg)
M079	-34.04	-33.01	41.68	42	-32.00	45.17	46
M082	-34.05	-32.98	41.71	47	-32.02	44.19	47
M083	-34.02	-33.01	42.26	41	-32.01	44.72	44
M089	-33.99	-33.00	42.57	53	-32.01	45.57	56
M092[2]	-34.97	-33.01	39.75	46	-32.04	42.15	47
M095	-34.00	-32.99	40.52	44	-31.99	45.33	46
M096[2]	-34.98	-33.02	43.66	57	-31.99	46.64	60
M097	-34.96	-33.99	40.00	50	-33.00	44.24	56

2. 1st detection resolution on M092-L and M096-L is 2 dB noise rise.

Figure 13: 5 GHz Noise Floor Database - RHCP & LHCP Transponders (May 1, 2014)

4.0 Noise Floor Measurement Scheduling

In support of both the 5 GHz Procedure Development and Long Term 5 GHz Constellation Survey, it was necessary to create a process to temporarily interrupt ground station commercial service operations in North America to eliminate any transmit power from the ground stations in the 5 GHz Band in the Globalstar satellite footprint.

4.1 Scheduling of Daytime Interruptions of Ground Station Operations

On a monthly basis Globalstar temporarily interrupts its ground station operations in North America in order to suppress communications traffic and allow the Globalstar satellites to measure the 5 GHz noise levels over the United States. To execute these brief interruptions in communications between Globalstar's ground stations and its satellites, the following requirements have to be met:

a. Satellites in view must be included in the calibrated subset of operational Globalstar satellites.
b. Satellite field of view must completely cover the continental United States during the measurement period.
c. The measurement period must be two minutes in duration and fall on one minute boundaries.
d. The measurement must be between the hours of 9:00 am ET and 8:00 pm ET so that normal daily noise floor in the U.S. is measured.

4.2 Implementation of Ground Station Interruptions

Typically, four satellites are selected for the monthly noise floor measurements. We also attempt to use a different set of satellites from the previous month so a valid statistical sample is maintained from all eight satellites.

Ground station commercial service interruptions are determined using the Analytical Graphics, Inc. (AGI) Satellite Toolkit (STK) software configured with all of the Globalstar satellite orbits. It was established that a two-minute pass (with margin) over any hypothetical ground point can be achieved by inserting a "sensor" on the simulated satellite with a 23-deg cone half-angle. Accordingly, each Globalstar satellite is so configured in STK. Measurement intervals are then determined as a coverage report from the center of the continental United States (Lincoln, Kansas), as shown in Figure 14 below. This coverage report is then fed into a script which imposes the above timing requirements, places the measurement on a one minute boundary, and filters the list to a small set of candidates.

Ground station commercial service operation interruption windows are then selected manually and, to the extent possible, different satellites are used from the previous month for the monthly noise floor measurement.

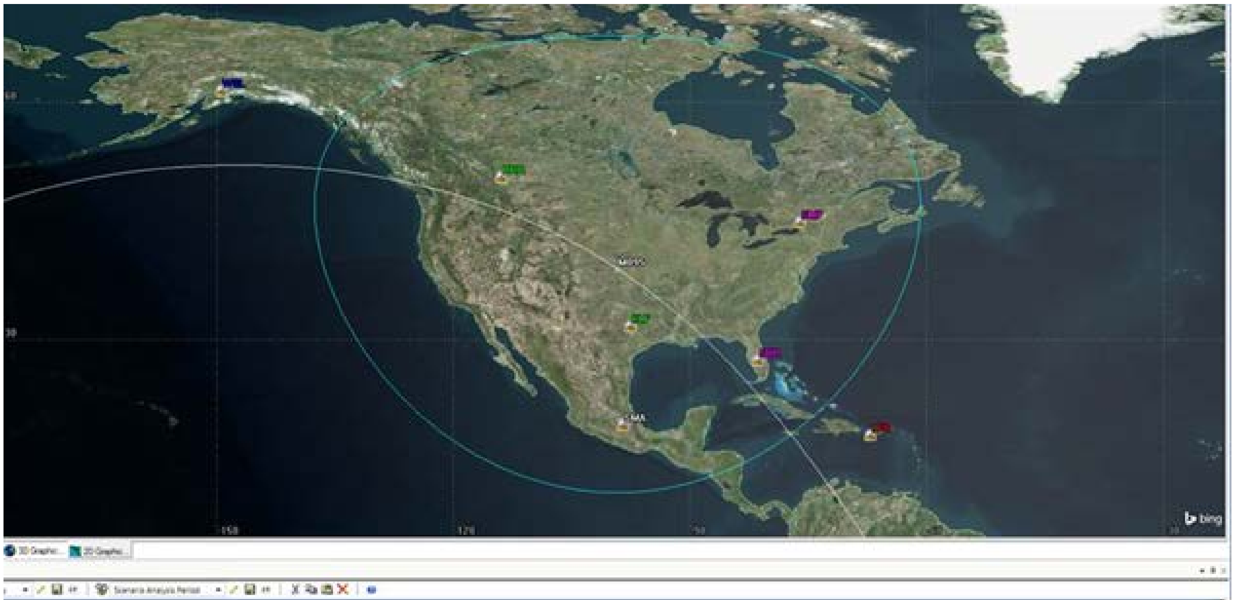


Figure 14: M095 Over Lincoln, Kansas - June 6, 2017 at 15:17:00 GMT

4.3 Long Term Monitoring of the Globalstar Constellation 5 GHz Noise Floor

The long term monitoring of the 5 GHz forward link noise floor was initiated on May 1, 2014. Since that date, we have repeated the 5 GHz Noise Floor measurements on a monthly basis, consisting of measurements at four satellites with eight transponders each month. As indicated above in paragraph 3.1.2, the Globalstar satellite feeder uplink transponders in effect measure the noise rise only in 1 dB increments. As a result, no noise rise was detectable by these satellites until the increase reached at least 1 dB, and no further noise rise above 1 dB was detectable until that increase reached at least 2 dB.

During the 34 month time period from May 2014 to February 2017, the Globalstar 5 GHz measured noise floor remained unchanged. Then, in February 2017, one Globalstar satellite's Left Hand Circular Polarization (LHCP) transponder indicated that the noise floor on that satellite had increased by 1.07 dB, which represented a "first detection" of a 1.0 dB, +/- 0.5 dB rise in the 5 GHz Noise Floor over North America. During the next six months, from February through July 2017, six additional Globalstar Satellite Transponders also indicated a "first detection" of a 1.0 dB, +/- 0.5 dB rise in the 5 GHz Noise Floor. As of April 5, 2018, nine Globalstar Transponders on seven different satellites are indicating a 1.0 dB +/- 0.5 dB.

In March 2017, a single Globalstar satellite flagged a "second detection" event indicating that the 5 GHz Noise Floor had experienced a 2.0 dB, +/- 0.5 dB rise. As of April 5, 2018, measurements on seven Globalstar satellite transponders are confirming the "second detection" of a 2.0 dB, +/- 0.5 increase in the 5 GHz Noise Floor. In total, at least one transponder on six of the eight satellites included in these measurements are being measured is exhibiting a 2.0 dB, +/- 0.5 dB increase in the noise floor.

It took almost three years – from May 2014 to February 2017 for the noise floor to rise by 1 dB. In comparison, it took less than two months for the next satellite noise floor to rise another dB, for an overall 2 dB noise rise. Subsequently, by August 2017 we had a total of five satellites indicating a 2 dB increase in the 5 GHz Noise Floor. The noise floor rise resulting from Outdoor U-NII-1 Wi-Fi deployments appears to be accelerating.

5.0 Additional 5 GHz Noise Floor Monitoring Locations

Initially, 5 GHz Noise Floor measurements were conducted only over Lincoln, Kansas during the daytime (Busy hours over North America). In August of 2017 we initiated daytime 5 GHz Noise Floor measurements over Europe and North Africa. We have also recently begun conducting night-time noise floor measurements over North America and daytime measurements over Australia. The preliminary results of these measurement categories are discussed below.

5.1 5 GHz Noise Level Over Blue Ocean

The plot shown in Figure 15 below summarizes the results of the noise floor measurements at the Globalstar satellites over North America versus the noise levels observed when Globalstar's satellites are over "Blue Ocean."

The plot shows the power level received at the M095 satellite at the input to the solid-state power amplifiers (SSPA) in a bandwidth 5096-5250 MHz versus time of day as the satellite travels from Blue Ocean (Figure 16), over the continental U.S. (Figure 17), and then back over Blue Ocean (Figure 18).

The part of the plot in the dotted-box corresponds to the portion of the orbit when the satellite is over the continental U.S. during the daytime. As described above, the noise floor when over Lincoln, Kansas is obtained by scheduling the Globalstar Gateway ground uplink to cease service for a two minute period, during which the noise floor can be measured at the satellite.

In the expanded view of the graph on the right, the noise floor as measured outside the United States over Blue Ocean is compared to the noise floor measured over Lincoln, Kansas, approximately in the geographic center of the U.S. No increase in the noise floor was observed over the Blue Ocean areas. In contrast, a noise floor difference, or noise rise, over the U.S. of 1 dB is readily observed.

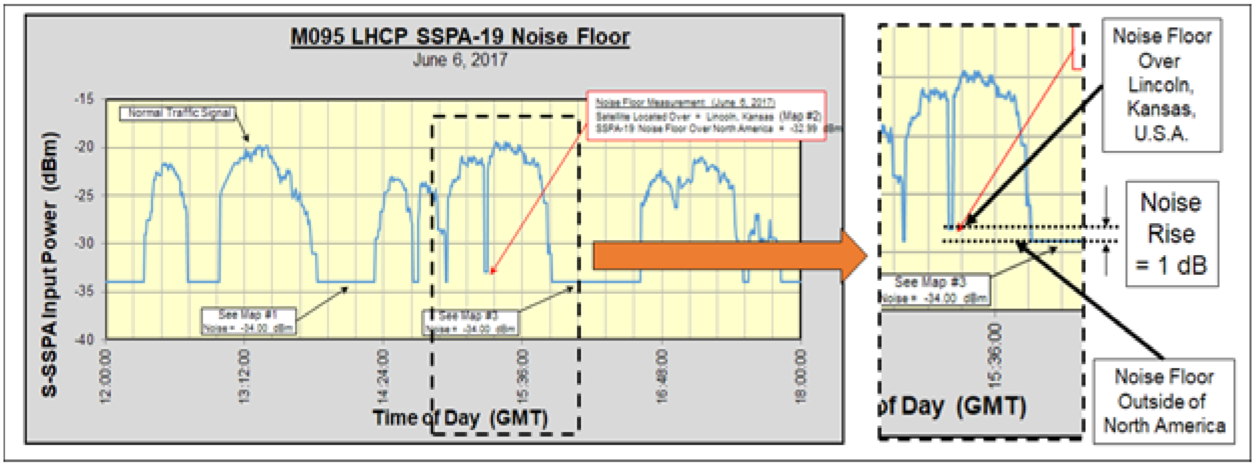


Figure 15: M095 - 5 GHz Noise Floor Increased By 1 dB vs. Blue Ocean

Figure 16: Map #1 – M095 Location 68 Minutes Prior To Lincoln, Kansa

Figure 17: Map #2 – M095 Location During 5 GHz Noise Floor Measurement

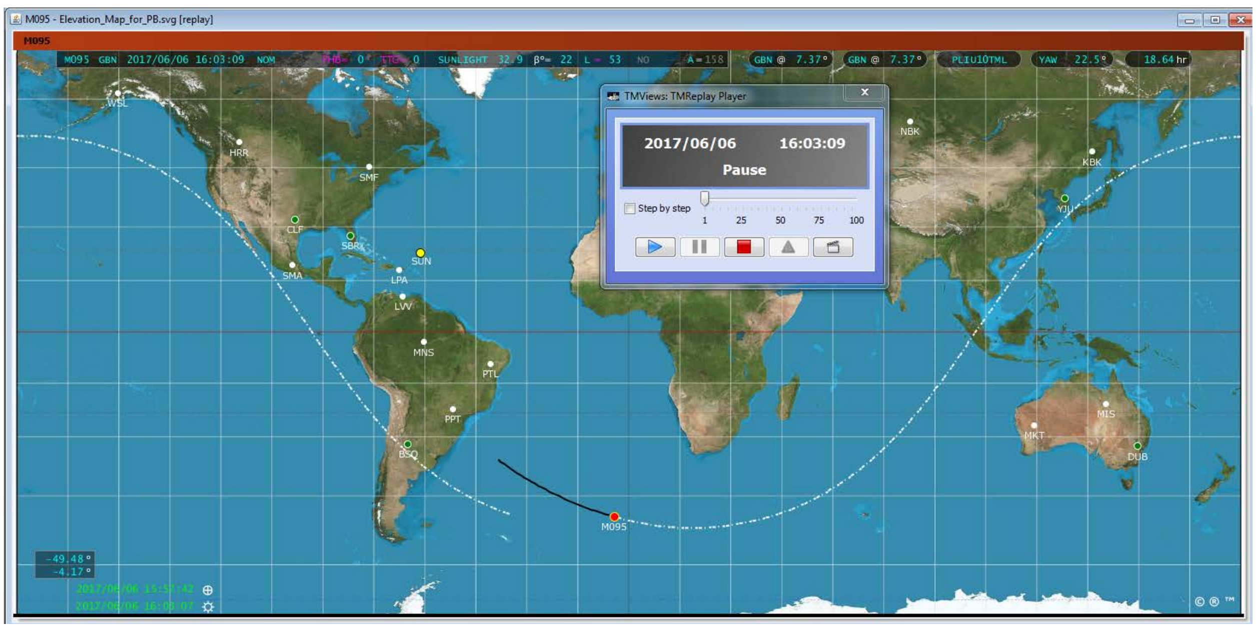


Figure 18: Map #3 – M095 Location 47 Minutes After 5 GHz Measurement

5.2 5 GHz Noise Floor Measurements Over Europe

European 5 GHz Noise Floor Measurement Description

Within the last few months, Globalstar has performed a sampling of 5 GHz Noise Floor measurements over the European land mass in order to confirm the 5 GHz Noise Floor rise over North America. While the European 5 GHz Noise Floor measurement methodology is similar to the measurements that are currently being conducted over North America, there are some differences between the measurement processes over these two continents.

First, for the measurements over Europe, we did not utilize an "Initial 5 GHz Noise Floor Calibration Database" developed specifically for the European region. Instead, we are utilizing the North American Noise Floor Reference Database, which may, or may not, be completely representative of the actual European 5 GHz Noise Floor. Second, the satellite location is different during the measurements over Europe. Given the parameters described here, we have set the noise floor measurement location at approximately 1150 kilometers SSW (South South West) of Ireland. The results of these measurements are shown in Figure 19 below.

Satellite ID & Polarization	Measurement Schedule (Date/Time)	Reference Noise Level (dBm)	Measurement Level (dBm)	Blue Ocean Noise Level (dBm)
M079-R	March 7, 2018 15:41:00	-35.04	-35.04	-35.04
M079-L	March 28, 2018 09:34:00	-34.04	-34.04	-34.04
M082-R	March 4, 2018 08:56:00	-34.98	-34.98	-34.98
M082-L	March 4, 2018 08:56:00	-34.05	-34.05	-34.05
M083-R	March 30, 2018 09:25:00	-35.02	-35.02	-35.02
M083-L	March 8, 2018 08:45:00	-34.02	-34.02	-34.02
M089-R	April 1, 2018 11:26:00	-35.02	-35.02	-35.02
M089-L	April 1, 2018 11:26:00	-33.99	-33.99	-33.99
M092-R	March 21, 2018 12:47:00	-34.98	-34.98	-34.98
M092-L	March 31, 2018 10:20:00	-34.97	-34.97	-34.97
M095-R	March 10, 2018 07:16:00	-35.03	-35.03	-35.03
M095-L	March 18, 2018 05:19:00	-34.00	-34.00	-34.00
M096-R	March 12, 2018 01:05:00	-35.03	-35.03	-35.03
M096-L	March 16, 2018 00:47:00	-34.98	-34.98	-34.98
M097-R	March 3, 2018 03:03:00	-35.01	-35.01	-35.01
M097-L	March 9, 2018 05:00:00	-34.96	-34.96	-34.96

Figure 19: 5 GHz Noise Floor Measurement Results Over Europe

5.3 5 GHz Night-Time Noise Floor Measurements Over Lincoln, Kansas

Recently, Globalstar has begun conducting night-time 5 GHz Noise Floor measurements. The rules governing the night-time measurements are similar to the daytime measurements, except for the time window.

The goal of the night-time measurements is to provide a comparison measurement to the daytime "Busy Hour" results. We have set the night-time candidate window to 07:00 to 11:00 GMT. This places the measurements in the middle of the night (approximately 3:00 AM Local time +/- 2 hours) over Lincoln, Kansas. Since the window for the night-time measurement is only 1/3 as large as the daytime window, we have only 1/3 of the chosen satellite candidates available during this 4 hour time period.

As of April 5, 2018, we have completed night-time 5 GHz Noise Floor measurements on 10 of the 16 designated satellite transponders. As shown in Figure 20, the measurements series is not yet complete, but the preliminary results indicate that there is a small decrease in the noise rise as compared to daytime results.

Nightime 5 GHz Noise Floor Results Over North America

(Measurements as of April 5, 2018)

Satellite ID & Polarization	Recent Measurement (Date/Time)	Reference Noise Level (dBm)	Current Measurement (dBm)	Current Noise Rise Results (dB)	Blue Ocean Noise Level (dBm)
M079-R		-35.04			-35.04
M079-L	February 11, 2018 08:34:00	-34.04	-33.01	1.03	-34.04
M082-R	April 3, 2018 09:21:00	-34.98	-34.02	0.96	-34.98
M082-L	April 3, 2018 09:21:00	-34.05	-32.98	1.07	-34.05
M083-R	January 22, 2018 07:45:00	-35.02	-33.99	1.03	-35.02
M083-L	April 1, 2018 12:41:00	-34.02	-33.01	1.01	-34.02
M089-R		-35.02			-35.02
M089-L		-33.99			-33.99
M092-R		-34.98			-34.98
M092-L		-34.97			-34.97
M095-R	March 5, 2018 07:12:00	-35.03	-33.04	1.99	-35.03
M095-L	March 5, 2018 07:12:00	-34.00	-32.99	1.01	-34.00
M096-R	March 6, 2018 08:19:00	-35.03	-33.96	1.07	-35.03
M096-L	March 20, 2018 01:021:00	-34.98	-32.99	1.99	-34.98
M097-R		-35.01			-35.01
M097-L	March 4, 2018 10:59:00	-34.96	-33.00	1.96	-34.96

Figure 20: Night-time 5 GHz Noise Floor Measurement Results Over North America

5.4 5 GHz Daytime Noise Floor Measurements Over Australia

Recently, HIBLEO-X has begun conducting daytime 5 GHz noise floor measurements over Australia. The rules governing these measurements are similar to the daytime measurements over the northern half of ITU-R, Region 2. The goal of the daytime Australian measurements is to provide a comparison measurement to the daytime "Busy Hour" measurements over the northern half of ITU-R, Region 2.

As of April 3, 2018, we have conducted noise floor measurements on five of our eight selected satellites. Measurements have been completed on seven of the ten RHCP/LHCP transponders available on these candidate satellites.

As of April 3, 2018, preliminary results are indicating that there is no increase in the noise floor over Australia when compared with "Blue Ocean" levels. Figure 21 below shows the target location and coverage of the satellites during the Australian measurements. These measurements are continuing on a monthly basis.

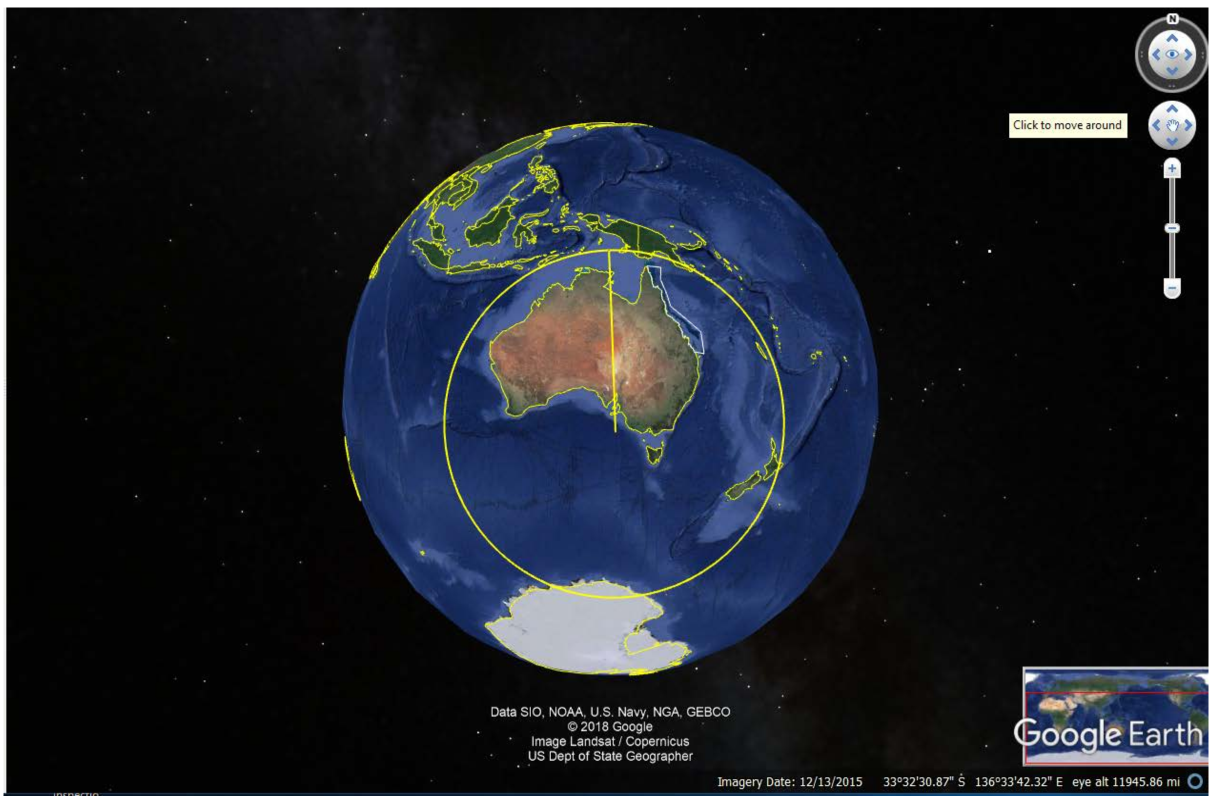


Figure 21: Satellite Coverage Over Australian 5 GHz Noise Floor Measurement

Appendix A

5 GHz Noise Floor Measurement Results Data

5 GHz Measurement Results Description

- Current Status for the 5 GHz Noise Floor Monitoring Project
- Description of the Individual Transponder Timeline Charts
- Description of the 5 GHz Outage Measurement Charts (Daytime)
- Description of the Blue Ocean Charts
- Description of the Reference 5 GHz - Noise Floor Database

Satellite Transponders Reporting a 1.0 dB, +/- 0.5 dB Increase in 5 GHz Noise Floor

- M079 - RHCP = 0.99 dB Noise Rise
- M082 - RHCP = 0.96 dB Noise Rise
- M082 - LHCP = 1.07 dB Noise Rise
- M083 - LHCP = 1.01 dB Noise Rise
- M089 - RHCP = 0.99 dB Noise Rise
- M089 - LHCP = 0.99 dB Noise Rise
- M092 - RHCP = 0.95 dB Noise Rise
- M095 - LHCP = 1.01 dB Noise Rise
- M096 - RHCP = 1.07 dB Noise Rise

Satellite Transponders Reporting a 2.0 dB, +/- 0.5 dB Increase in 5 GHz Noise Floor

- M079 - LHCP = 2.04 dB Noise Rise
- M083 - RHCP = 2.01 dB Noise Rise
- M092 – LHCP = 1.96 dB Noise Rise
- M095 - RHCP = 1.99 dB Noise Rise
- M096 – LHCP = 1.96 dB Noise Rise
- M097 – RHCP = 1.99 dB Noise Rise
- M097 - LHCP = 1.96 dB Noise Rise

5 GHz Noise Floor Project Current Status

As of April 3, 2018 there are nine Globalstar Satellite Transponders on seven different satellites reporting at least a 1.0 dB, +/- 0.5 dB increase in the 5 GHz Noise Floor while over North America. Additionally, there are seven Satellite Transponders on six different satellites reporting a 2.0 dB, +/- 0.5 dB increase in the 5 GHz Noise Floor.

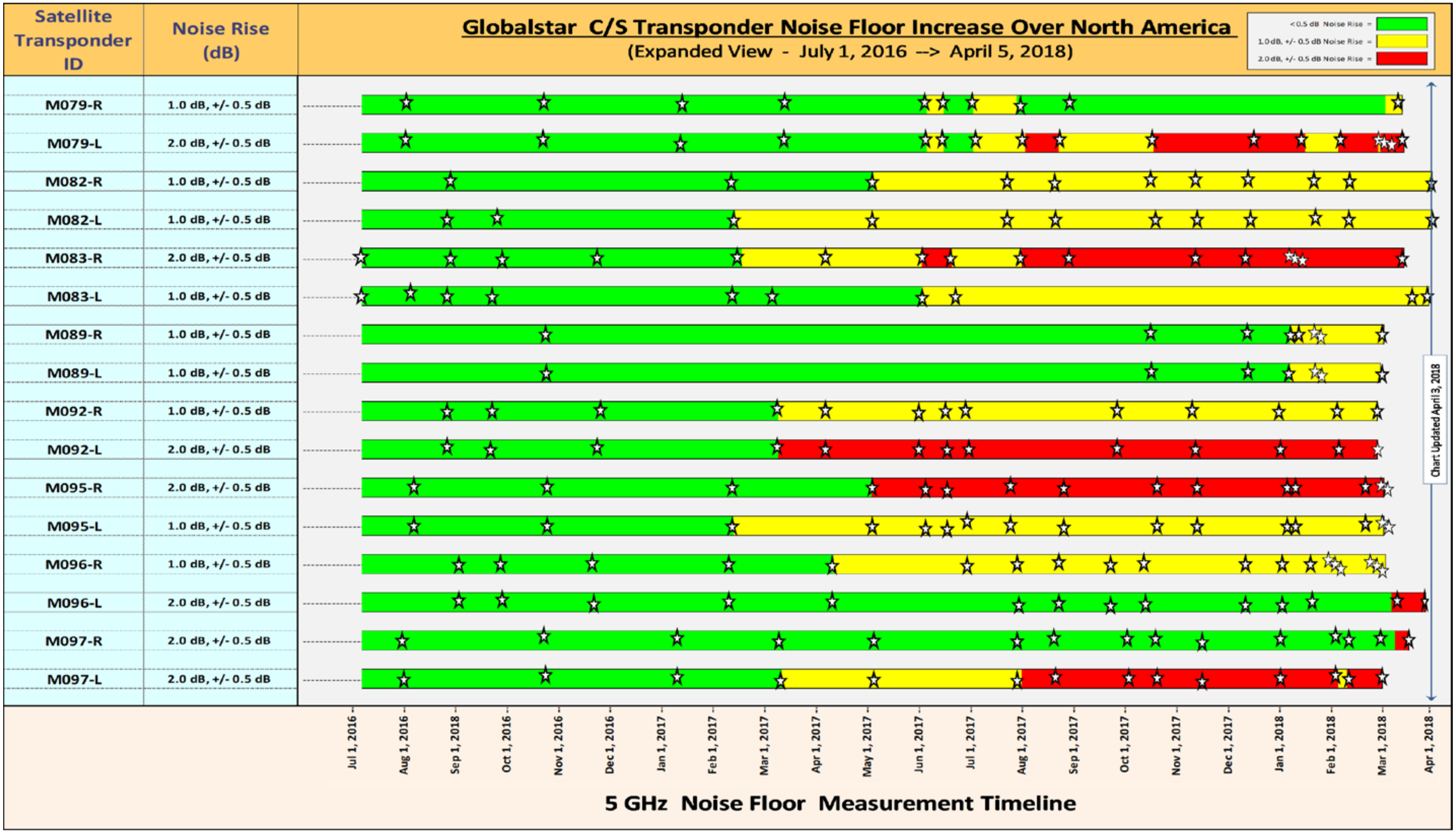
The following pages of Appendix A contain five types of charts for reporting of the noise floor rise of the 16 Satellite Transponders identified above on page A-1. The five types of charts are:

1. 5 GHz Noise Floor Results Over North America (Daytime)
2. Expanded 5 GHz C/S Noise Floor Summary Timeline (With Measurement Times)
3. Individual Satellite 5 GHz Noise Floor Measurement Timeline Tables
4. Daytime Measurement Charts
5. Expanded View Blue Ocean Charts

Daytime 5 GHz Noise Floor Results Over North America

(Recent Measurements)

Satellite ID & Polarization	Recent Measurement (Date/Time)	Reference Noise Level (dBm)	Current Measurement (dBm)	Current Noise Rise Results (dB)	Blue Ocean Noise Level (dBm)
M079-R	March 16, 2018 09:21:00	-35.04	-34.05	0.99	-35.04
M079-L	February 13, 2018 20:23:00	-34.04	-32.00	2.04	-34.04
M082-R	April 3, 2018 16:15:00	-34.98	-34.02	0.96	-34.98
M082-L	April 3 13, 2018 16:15:00	-34.05	-32.98	1.07	-34.05
M083-R	March 17, 2018 17:21:00	-35.02	-33.01	2.01	-35.02
M083-L	April 1, 2018 12:41:00	-34.02	-33.01	1.01	-34.02
M089-R	January 9, 2018 20:29:00	-35.02	-34.03	0.99	-35.02
M089-L	January 9, 2018 20:29:00	-33.99	-33.00	0.99	-33.99
M092-R	March 1, 2018 17:21:00	-34.98	-34.03	0.95	-34.98
M092-L	March 1, 2018 17:21:00	-34.97	-33.01	1.96	-34.97
M095-R	March 5, 2018 07:12:00	-35.03	-33.04	1.99	-35.03
M095-L	March 5, 2018 07:12:00	-34.00	-32.99	1.01	-34.00
M096-R	March 6, 2018 08:19:00	-35.03	-33.96	1.07	-35.03
M096-L	March 18, 2018 22:05:00	-34.98	-33.02	1.96	-34.98
M097-R	March 20, 2018 01:01:00	-35.01	-33.02	1.99	-35.01
M097-L	January 6, 2018 19:47:00	-34.96	-33.00	1.96	-34.96



5 GHz C/S Noise Floor Summary Timeline (With Approximate Measurement Dates)

Description of the Individual Satellite Timeline Charts

Appendix A contains a 5 GHz Measurement Timeline chart for each of the Satellite Transponders listed above. Each of these charts contains the details for the measurements performed from May 1, 2014 to the present. The five columns in these charts are defined as follows:

1. Satellite ID and Measurement Date
2. Reference Noise Floor Level from May 1, 2014 Database
3. SSPA Measurement Level recorded during Satellite Outage
4. Indicated 5 GHz Noise Floor Increase (i.e. Col 3 – Col 2)
5. Descriptive comments as appropriate.

Description of the 5 GHz Daytime Measurement Charts

The 5 GHz Outage Measurement charts are a Telemetry Replay of the Satellite SSPA Input Power telemetry for the RHCP and/or LHCP captured during a short time period surrounding the actual two minute No Traffic outage period. In this case the view is zoomed in so that we can see the individual telemetry capture points. On each chart, we have labeled the "Reference" Noise Level and the measured indication of specific noise rise.

Description of the Blue Ocean Charts

In addition to the 5 GHz Outage Measurements charts, we have attached an Expanded View chart for each satellite transponder. These charts are also a Telemetry Replay of the SSPA Input Power Levels for approximately one hour prior to the 5 GHz Outage until one hour after the measurement (i.e. slightly more than one orbit). The purpose of the chart is to compare the "Blue Ocean" SSPA Input power levels to the Reference Levels shown in the 5 GHz Reference Database. Thus far, the Blue Ocean levels are identical to the Reference Database levels in all cases.

Description of the Reference 5 GHz - Noise Floor Database

The 5 GHz Master Noise Floor Database contains relevant noise floor data for each of the 24 RHCP and 24 LHCP Transponders in the Globalstar Satellite Constellation. The Reference 5 GHz Noise Floor Database used in this White Paper contains data for only eight of the 24 satellites, as follows: M079, M082, M083, M089, M092, M095, M096, and M097. This Database was populated during the Characterization and Calibration phase of this project in late 2013 and early 2014. The entries in the database were initialized for the 5 GHz Noise Floor monitoring phase of the project on May 1, 2014.

Each Satellite Transponder line entry in the Reference Database consists of consists of eight columns of data, as follows:

1. Satellite ID
2. Reference "No Traffic" SSPA Input Power Level (dBm)

3. 1.0 dB, +/- 0.5 dB Noise Rise for 1st Detection Level (SSPA Input Power in dBm)
4. Equivalent 802.11ac Ground EIRP to produce a 1 dB rise in Noise Level
5. User Elevation Angle at Calibration time (Used to calculate FSL)
6. 2.0 dB, +/- 0.5 dB Noise Rise for 2nd Detection Level (SSPA Input Power in dBm)
7. Equivalent 802.11ac Ground EIRP to produce a 2 dB rise in Noise Level
8. User Elevation Angle at Calibration time (Used to calculate FSL)

RHCP Noise Floor Reference Data

Sat ID	Reference Noise Floor (dBm)	1 dB Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	User Angle (deg.)	2 dB Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	User Angle (deg.)
M079	-35.04	-34.05	41.88	44	-33.04	45.11	46
M082	-34.98	-34.02	40.83	43	-33.04	44.32	47
M083	-35.02	-33.99	42.26	41	-33.01	44.72	44
M089	-35.02	-34.03	40.27	50	-33.01	44.30	56
M092[1]	-34.98	-34.03	39.75	46	-32.97	42.15	47
M095	-35.03	-33.04	40.52	42	-31.99	45.33	46
M096	-35.03	-33.96	39.49	57	-33.01	43.37	60
M097	-35.01	-33.02	41.60	53	-32.01	44.96	56

1. M092 RHCP Reference Noise Floor synchronized with 2014-2018 Blue Ocean value 11/31/2017

LHCP Noise Floor Reference Data

Sat ID	Reference Noise Floor (dBm)	1 dB Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	User Angle (deg.)	2 dB Noise Rise Det. Level (dBm)	802.11ac Ground EIRP Equivalent (dBw)	User Angle (deg.)
M079	-34.04	-33.01	41.68	42	-32.00	45.17	44
M082	-34.05	-32.98	41.71	47	-32.02	44.19	53
M083	-34.02	-33.01	42.26	41	-32.01	44.72	44
M089	-33.99	33.00	42.57	53	-32.01	45.57	57
M092[2]	-34.97	-33.01	39.63	46	-31.53	43.51	47
M095	-34.00	-32.99	40.52	44	-31.99	45.33	46
M096	-34.98	-33.02	43.66	57	-31.99	46.64	60
M097	-34.96	-33.99	40.00	50	33.00	44.24	55

1. M092 LHCP Reference Noise Floor synchronized with 2014-2018 Blue Ocean value 11/31/2017

Reference 5 GHz - Noise Floor Database – Sixteen Designated Satellite Transponders

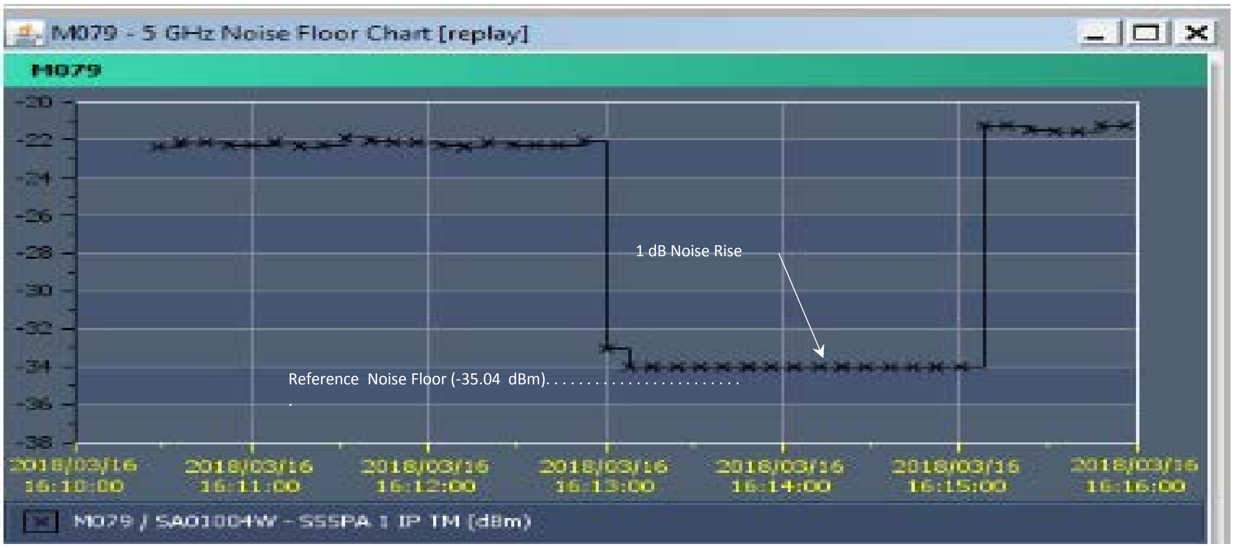
Individual Satellite C/S Transponder Noise Floor Measurement Details

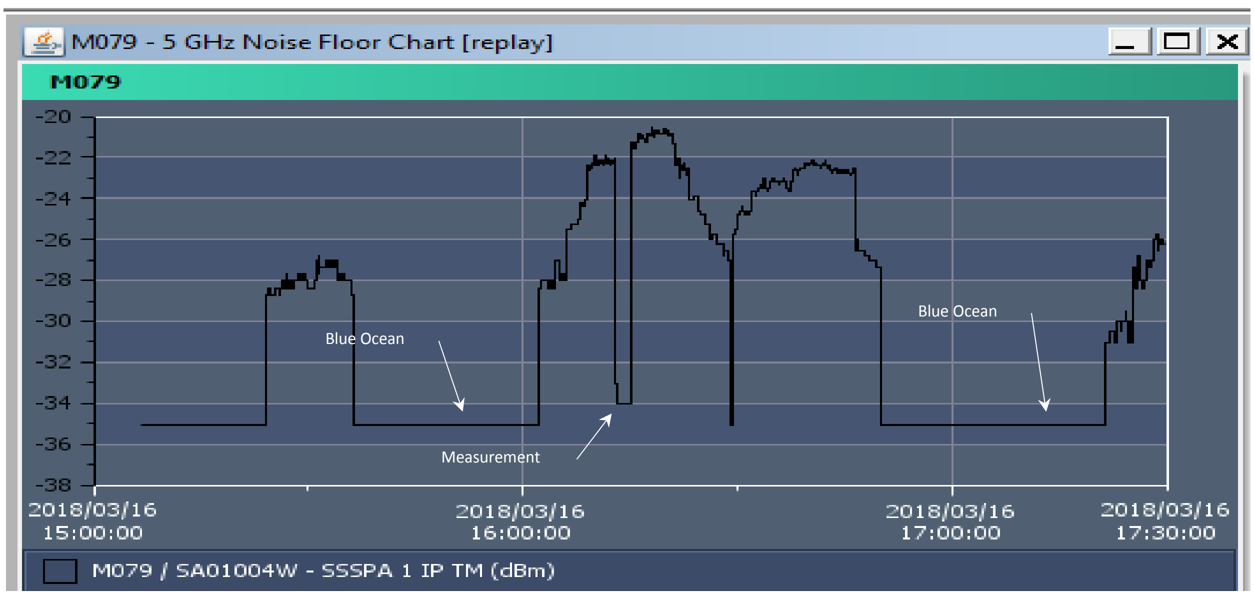
The following 32 pages list the measurement details for each of the 16 satellite transponders that were chosen for the 5 GHz Noise Floor Monitoring effort. There are three specific items provided for each transponder. The first item is a timeline of the dates, results, and comments for each of the measurements on that Transponder. The second item is a telemetry replay chart of a recent measurement which depicts the current 5 GHz Noise Rise status. The third item is a “Blue Ocean” chart which depicts the 5 GHz Noise Floor level approximately one hour before and one hour after the measurement shown in Item # 2.

M079 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M079-RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/05/20	14:01:00	-35.04	-35.04	0.00	No noise floor rise detected
2014/06/23	22:26:00	-35.04	-35.04	0.00	
2014/07/14	16:19:00	-35.04	-35.04	0.00	
2014/08/11	15:33:00	-35.04	-35.04	0.00	
2014/09/26	21:02:00	-35.04	-35.04	0.00	
2014/10/15	15:24:00	-35.04	-35.04	0.00	
2014/10/24	20:16:00	-35.04	-35.04	0.00	
2015/02/11	14:13:00	-35.04	-35.04	0.00	
2015/06/09	00:09:00	-35.04	-35.04	0.00	
2015/07/30	17:33:00	-35.04	-35.04	0.00	
2015/09/23	19:50:00	-35.04	-35.04	0.00	
2015/10/23	18:35:00	-35.04	-35.04	0.00	
2015/12/23	19:25:00	-35.04	-35.04	0.00	
2016/02/10	12:32:00	-35.04	-35.04	0.00	
2016/04/06	21:38:00	-35.04	-35.04	0.00	
2016/05/04	14:49:00	-35.04	-35.04	0.00	
2016/06/30	16:37:00	-35.04	-35.04	0.00	
2016/07/28	15:51:00	-35.04	-35.04	0.00	
2016/10/21	16:54:00	-35.04	-35.04	0.00	
2017/01/12	18:26:00	-35.04	-35.04	0.00	No noise floor rise detected
2017/03/10	20:36:00	-35.04	-35.04	0.00	No noise floor rise detected
2017/04/07	19:50:00	-35.04	-35.04	0.00	No noise floor rise detected
2017/06/05	21:09:00	-35.04	-34.05	0.99	First detection of a 1 dB noise rise
2017/06/15	18:43:00	-35.04	-35.04	0.00	Toggling between 0 dB and 1 dB noise rise
2017/07/03	20:23:00	-35.04	-34.05	0.99	Indicates a 1 dB noise rise.
2017/07/28	13:18:00	-35.04	-34.05	0.99	Indicates a 1 dB noise rise.
2018/03/16	16:13:00	-35.04	-34.05	0.99	Indicates a 1 dB noise rise.
2018/03/29	20:07:00	-35.04	-34.05	0.99	Indicates a 1 dB noise rise.

M079 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)



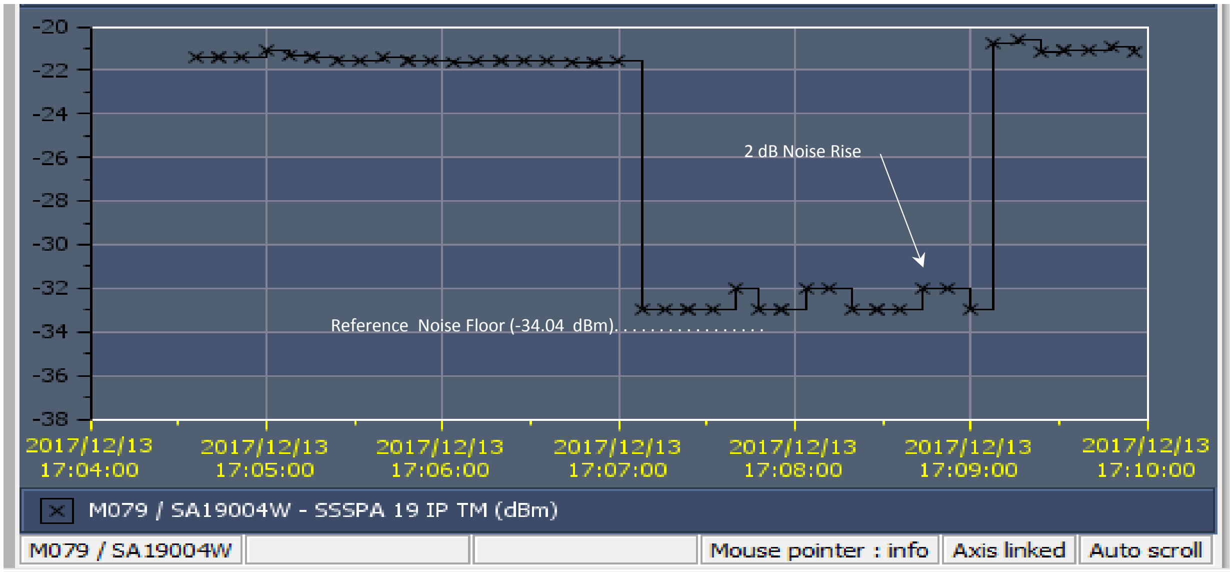


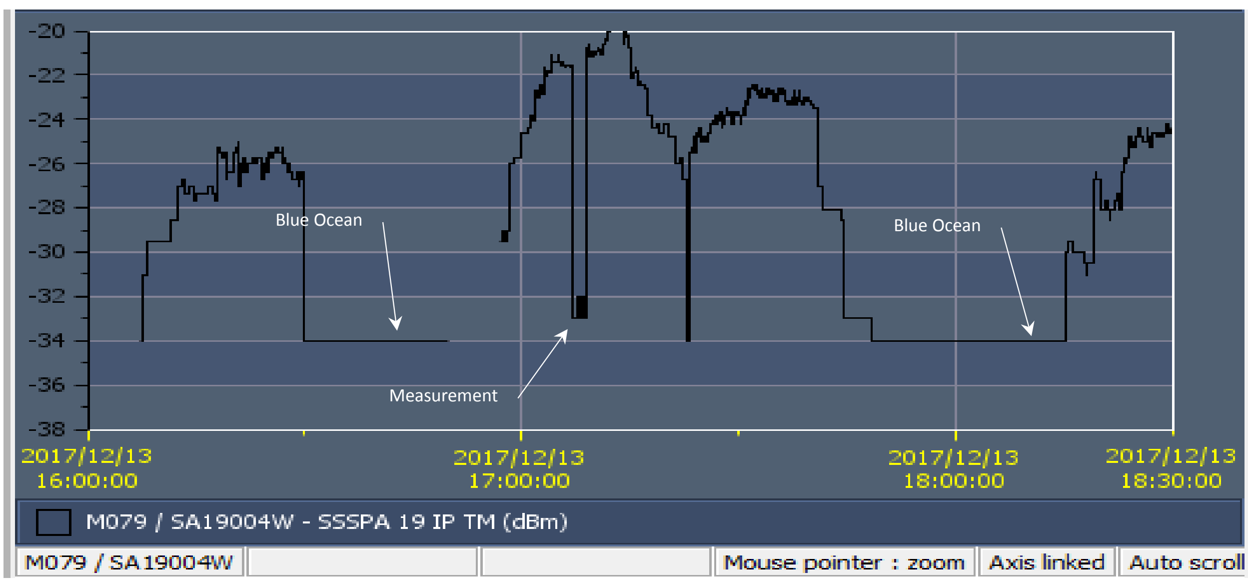
M079 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M079-LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/05/20	14:01:00	-34.04	-34.98	-0.94	Noise floor decreased 1 dB from Ref. Database
2014/06/23	22:26:00	-34.04	-34.04	0.00	Noise Floor Returned to Ref. Database level.
2014/07/14	16:19:00	-34.04	-34.04	0.00	
2014/08/11	15:33:00	-34.04	-34.98	-0.94	Noise Floor decreased 1 dB from Ref. Database
2014/09/26	21:02:00	-34.04	-34.04	0.00	Noise Floor Returned to Ref. Database level.
2014/10/15	15:24:00	-34.04	-34.04	0.00	
2014/10/24	20:16:00	-34.04	-34.04	0.00	
2015/02/11	14:13:00	-34.04	-34.98	-0.94	Noise Floor decreased 1 dB from Ref. Database
2015/06/09	00:09:00	-34.04	-34.04	0.00	Noise Floor Returned to Ref. Database level.
2015/07/30	17:33:00	-34.04	-34.04	0.00	
2015/09/23	19:50:00	-34.04	-34.04	0.00	
2015/10/23	18:35:00	-34.04	-34.04	0.00	
2015/12/23	19:25:00	-34.04	-34.04	0.00	
2016/02/10	12:32:00	-34.04	-34.04	0.00	
2016/04/06	21:38:00	-34.04	-34.04	0.00	
2016/05/04	14:49:00	-34.04	-34.04	0.00	
2016/06/30	16:37:00	-34.04	-34.04	0.00	
2016/07/28	15:51:00	-34.04	-34.04	0.00	
2016/10/21	16:54:00	-34.04	-34.04	0.00	
2017/01/12	18:26:00	-34.04	-34.04	0.00	
2017/03/10	20:36:00	-34.04	-34.04	0.00	No Noise Rise Detected
2017/04/07	19:50:00	-34.04	-34.04	0.00	No Noise Rise Detected
2017/06/05	21:09:00	-34.04	-33.01	1.03	First detection of 1 dB noise rise
2017/06/15	18:43:00	-34.04	-34.04	0.00	Toggling between 0 dB and 1 dB noise rise
2017/07/03	20:23:00	-34.04	-33.01	1.03	Toggling between 0 dB and 1 dB noise rise
2017/08/03	11:50:00	-34.04	-32.00	2.04	First detection of 2 dB noise rise
2017/08/23	23:39:00	-34.04	-33.01	1.03	Toggling between 1 dB and 2 dB noise rise
2017/10/02	19:58:00	-34.04	-33.01	1.03	Toggling between 1 dB and 2 dB noise rise
2017/10/19	14:49:00	-34.04	-32.00	2.04	Current measurements indicate a 2 dB noise rise
2017/12/13	17:07:00	-34.04	-32.00	2.04	Current measurements indicate a 2 dB noise rise
2018/01/05	18:36:00	-34.04	-32.00	2.04	Current measurements indicate a 2 dB noise rise
2018/01/18*	08:21:00	-34.04	-33.01	1.03	Current measurements indicate a 2 dB noise rise
2018/01/20*	07:52:00	-34.04	-33.01	1.03	Current measurements indicate a 2 dB noise rise
2018/01/22*	07:23:00	-34.04	-33.01	1.03	Current measurements indicate a 2 dB noise rise
2018/20/07*	09:32:00	-34.04	-32.00	2.04	Toggling between 1 dB and 2 dB noise rise
2018/02/11*	08:34:00	-34.04	-33.01	1.03	Toggling between 1 dB and 2 dB noise rise
2018/02/13*	08:04:00	-34.04	-32.00	2.04	Toggling between 1 dB and 2 dB noise rise
2018/03/03*	20:23:00	-34.04	-33.01	1.03	Toggling between 1 dB and 2 dB noise rise
2018/03/29	20:07:00	-34.04	-33.01	1.03	Current measurements indicate a 1 dB noise rise

* Night-time measurement

M079 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)



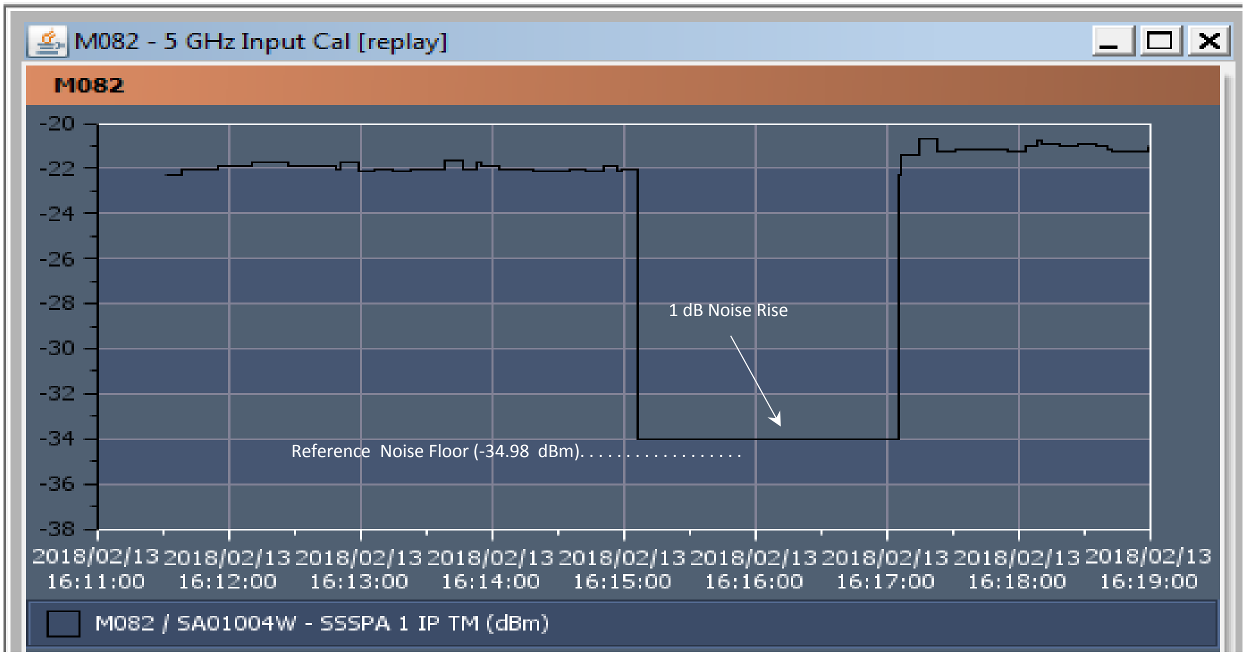


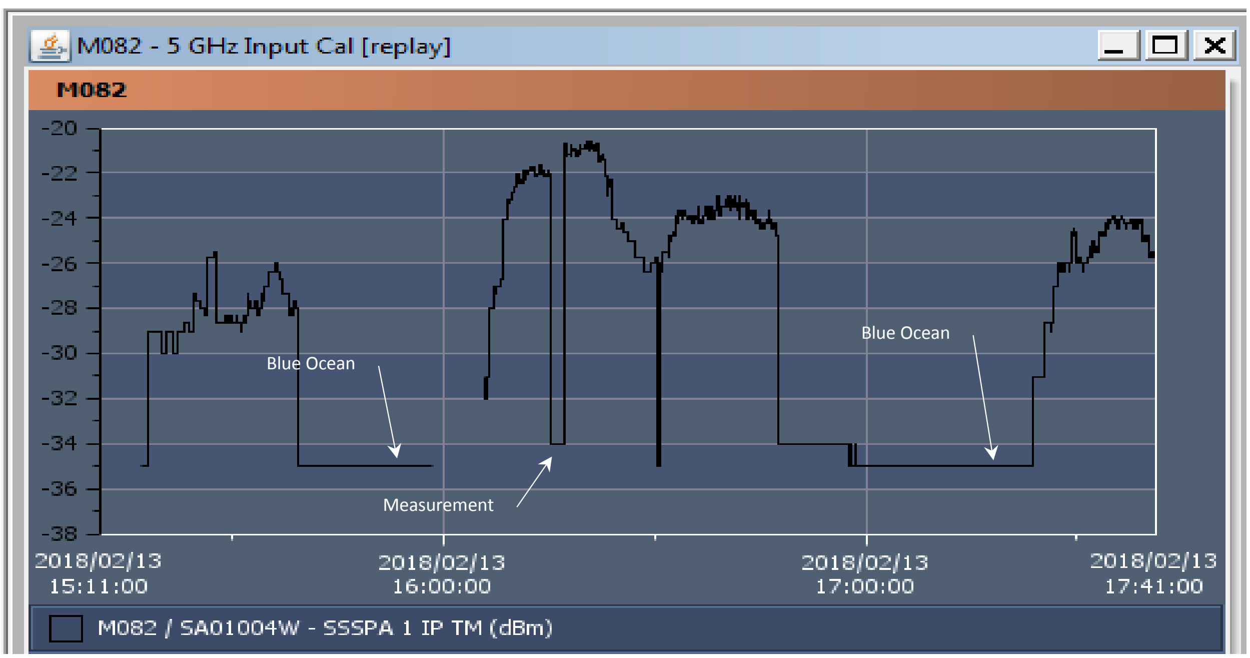
M082 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M082-RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/06/02	18:35:00	-34.98	-34.98	0.00	No noise floor rise detected
2014/08/27	20:23:00	-34.98	-34.98	0.00	
2014/09/03	17:41:00	-34.98	-34.98	0.00	
2014/09/17	14:16:00	-34.98	-34.98	0.00	
2015/01/14	13:04:00	-34.98	-34.98	0.00	
2015/03/13	21:43:00	-34.98	-34.98	0.00	
2015/05/11	23:00:00	-34.98	-34.98	0.00	
2015/07/03	15:09:00	-34.98	-34.98	0.00	
2015/08/27	17:27:00	-34.98	-34.98	0.00	
2015/11/24	17:31:00	-34.98	-34.98	0.00	
2016/02/12	20:46:00	-34.98	-34.98	0.00	
2016/03/15	19:02:00	-34.98	-34.98	0.00	
2016/05/05	22:18:00	-34.98	-34.98	0.00	
2016/06/29	13:57:00	-34.98	-34.98	0.00	
2016/08/25	15:46:00	-34.98	-34.98	0.00	
2016/09/22	15:00:00	-34.98	---	---	Gw configuration incorrect, all traffic not removed
2017/02/10	19:06:00	-34.98	-34.98	0.00	No noise floor rise detected
2017/05/04	20:25:00	-34.98	-34.02	0.96	First detection of a 1 dB noise rise
2017/07/26	21:57:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2017/08/23	15:07:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2017/10/23	22:01:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2017/11/18	15:41:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2017/12/18	14:26:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/01/22	21:36:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/02/13	16:15:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/03/28*	10:49:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/03/30*	10:20:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/04/01*	09:51:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.
2018/04/03*	09:21:00	-34.98	-34.02	0.96	Indicates a 1 dB noise rise.

* Night-time measurement

M082 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)



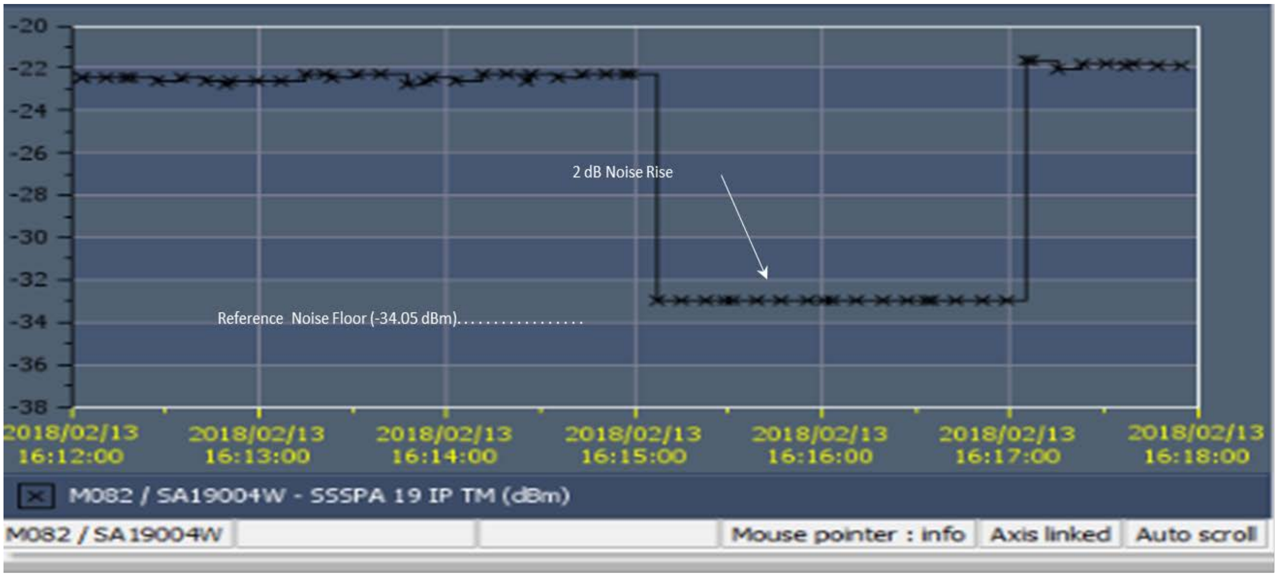


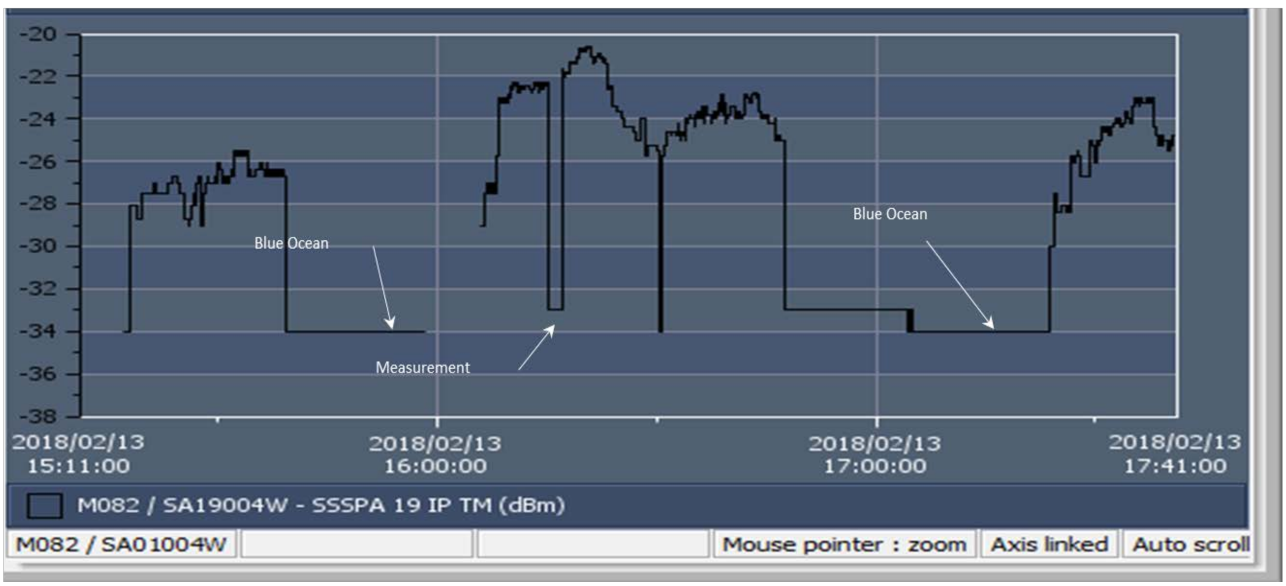
M082 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M082-LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/06/02	18:35:00	-34.05	-34.05	0.00	No noise floor rise detected
2014/08/27	20:23:00	-34.05	-34.05	0.00	
2014/09/03	17:41:00	-34.05	-34.05	0.00	
2014/09/17	14:16:00	-34.05	-34.05	0.00	
2015/01/14	13:04:00	-34.05	-34.05	0.00	
2015/03/13	21:43:00	-34.05	-34.05	0.00	
2015/05/11	23:00:00	-34.05	-34.05	0.00	
2015/07/03	15:09:00	-34.05	-34.05	0.00	
2015/08/27	17:27:00	-34.05	-34.05	0.00	
2015/11/24	17:31:00	-34.05	-34.05	0.00	
2016/02/12	20:46:00	-34.05	-34.05	0.00	
2016/03/15	19:02:00	-34.05	-34.05	0.00	
2016/05/05	22:18:00	-34.05	-34.05	0.00	
2016/06/29	13:57:00	-34.05	-34.05	0.00	
2016/08/25	15:46:00	-34.05	-34.05	0.00	
2016/09/22	15:00:00	-34.05	---	---	Gw configuration incorrect, all traffic not removed
2017/02/10	19:06:00	-34.05	-32.98	1.07	First detection of a 1 dB noise rise
2017/05/04	20:25:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2017/07/26	21:57:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2017/08/23	15:07:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2017/10/23	22:01:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2017/11/18	15:41:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2017/12/18	14:26:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/01/22	21:36:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/02/13	16:15:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/03/28*	10:49:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/03/30*	10:20:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/04/01*	09:51:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.
2018/04/03*	09:21:00	-34.05	-32.98	1.07	Indicates a 1 dB noise rise.

* Night-time measurement

M082 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)



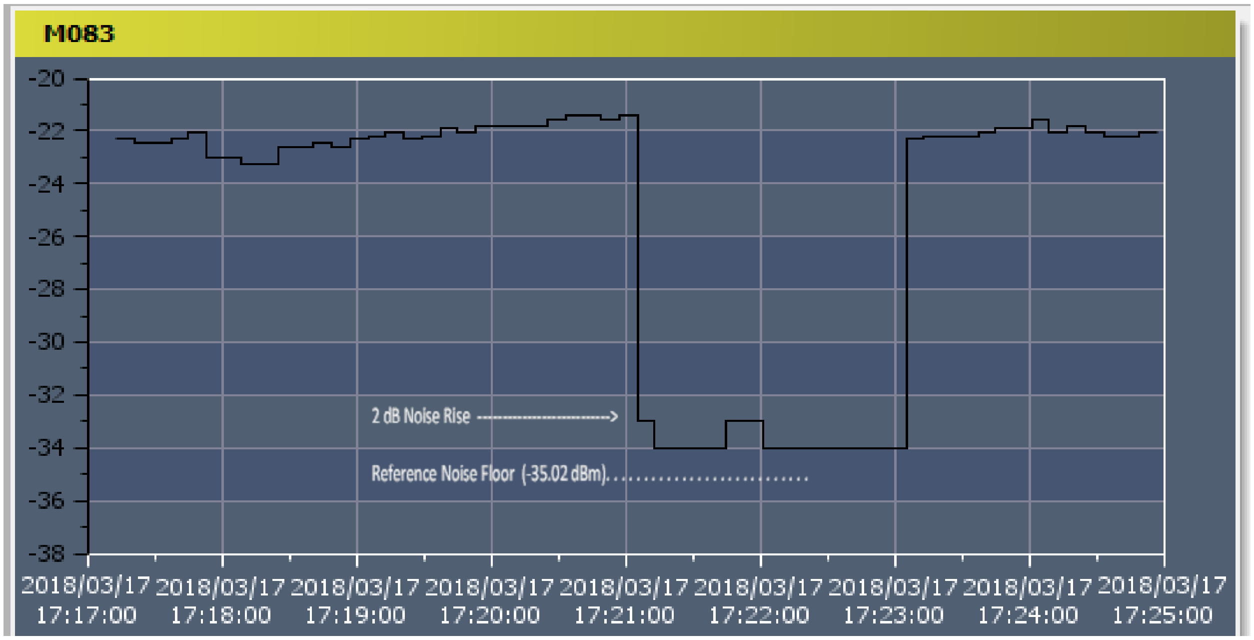


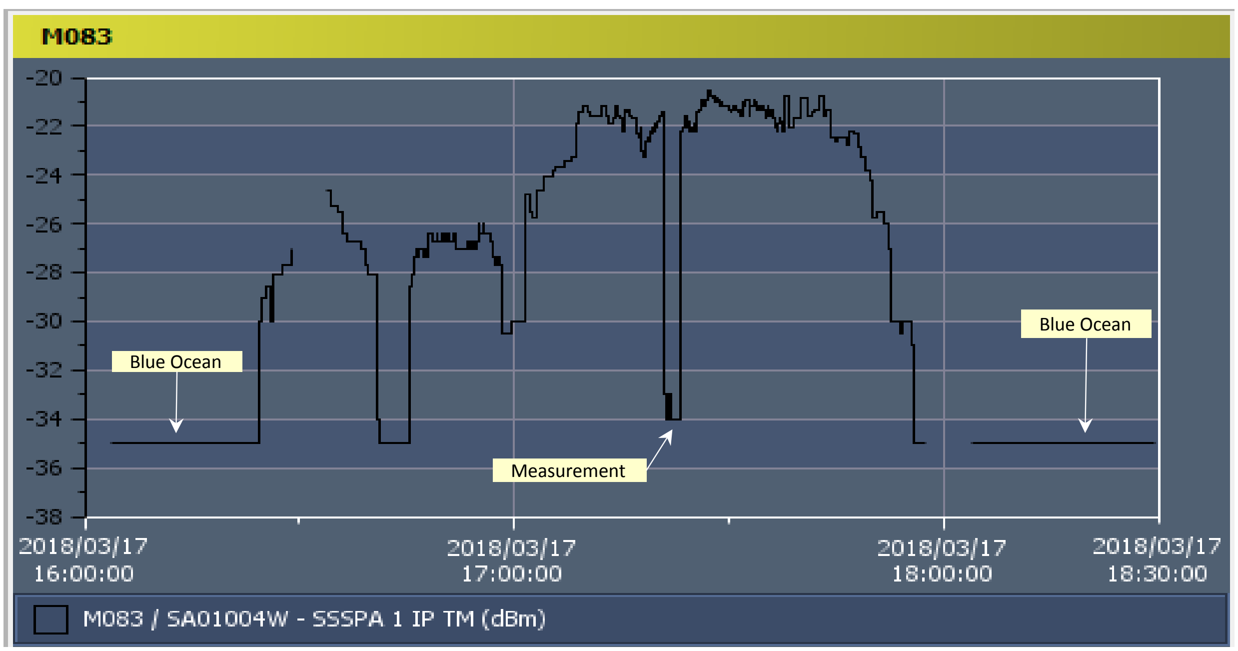
M083 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M083- RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/06/09	20:32:00	-35.02	-35.02	0.00	No Noise Rise Detected
2014/07/07	19:46:00	-35.02	-35.02	0.00	
2014/07/24	14:37:00	-35.02	-35.02	0.00	
2014/09/10	19:37:00	-35.02	---	---	Gw configuration incorrect, all traffic not removed
2014/09/23	15:27:00	-35.02	-35.02	0.00	
2014/10/17	15:40:00	-35.02	-35.02	0.00	
2014/10/23	14:12:00	-35.02	-35.02	0.00	
2015/03/12	17:30:00	-35.02	-35.02	0.00	
2015/06/08	18:51:00	-35.02	-35.02	0.00	
2015/07/29	11:28:00	-35.02	-33.99	1.03	Single event, not verified by other satellites
2015/09/25	20:06:00	-35.02	-35.02	0.00	
2016/01/13	14:02:00	-35.02	-35.02	0.00	
2016/03/16	22:27:00	-35.02	-35.02	0.00	
2016/06/09	15:26:00	-35.02	-35.02	0.00	
2016/07/01	16:08:00	-35.02	-35.02	0.00	
2016/08/24	19:40:00	-35.02	-35.02	0.00	
2016/09/23	18:25:00	-35.02	-35.02	0.00	
2016/11/21	19:44:00	-35.02	-35.02	0.00	No Noise Rise Detected
2017/02/14	20:47:00	-35.02	-33.99	1.03	First detection of 1 dB noise rise
2017/04/06	13:24:00	-35.02	-33.99	1.03	Repeat 1dB noise rise
2017/06/02	15:12:00	-35.02	-33.01	2.01	First detection of 2dB noise rise
2017/06/20	16:53:00	-35.02	-33.99	1.03	Toggling between 1 dB and 2 dB noise rise
2017/08/01	23:20:00	-35.02	-33.01	2.01	Toggled back to a 2 dB noise rise
2017/08/29	16:31:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2017/09/29	14:01:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2017/11/16	19:01:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2017/12/14	18:15:00	-35.02	-33.01	2.01	Indicating a possible 3dB precursor
2018/01/18*	08:43:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2018/01/20*	08:14:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2018/01/22*	07:45:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise
2018/02/09	20:04:00	-35.02	---	---	Gateway malfunction, no measurement
2018/03/17	17:21:00	-35.02	-33.01	2.01	Current measurements indicate a 2 dB noise rise

* Night-time Measurement

M083 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)

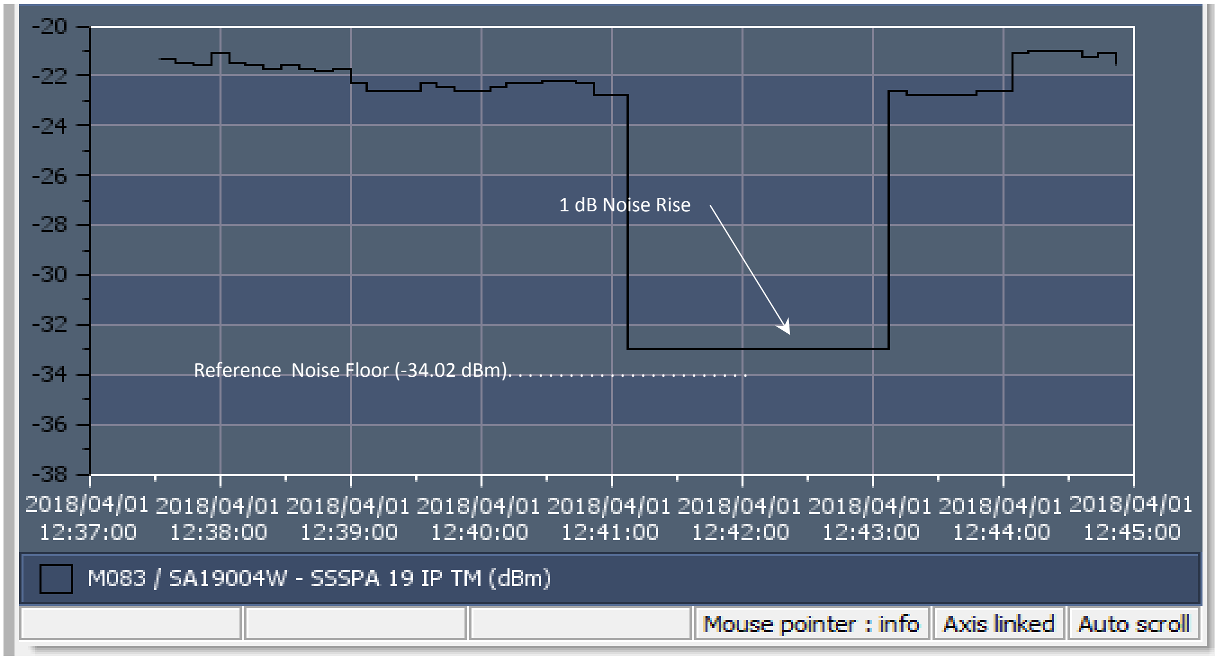


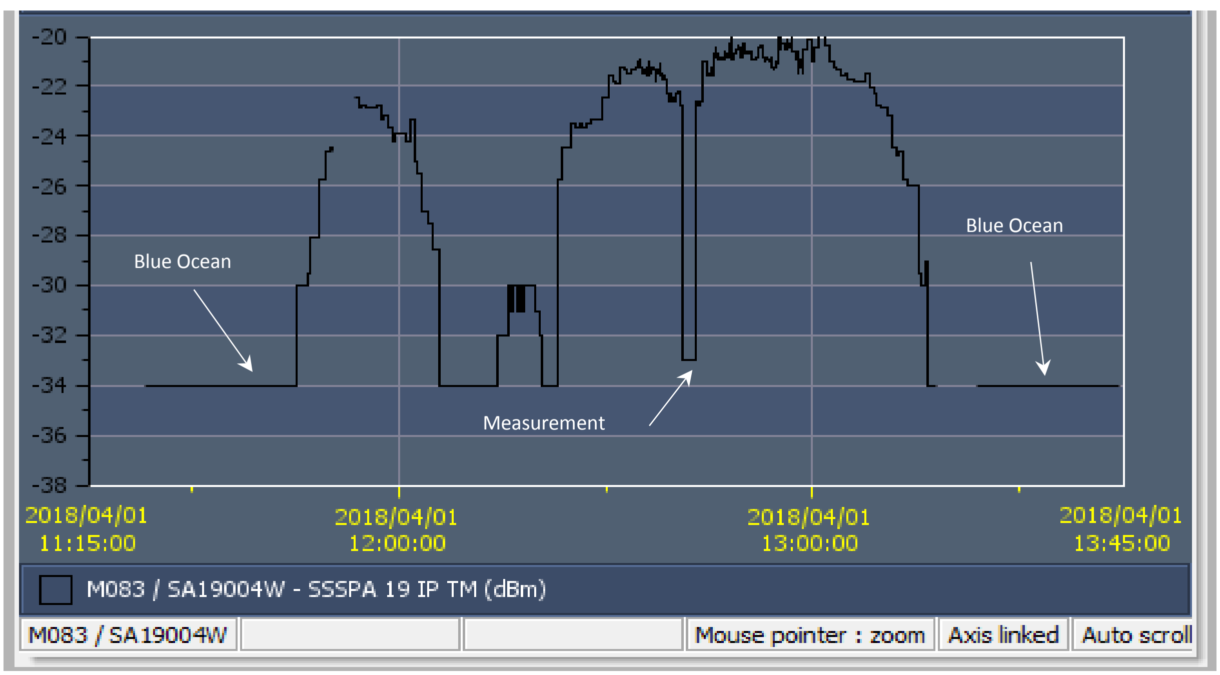


M083 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M083-LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/06/09	20:32:00	-34.02	-34.02	0.00	No noise floor rise detected
2014/07/07	19:46:00	-34.02	-34.02	0.00	
2014/07/24	14:37:00	-34.02	-34.02	0.00	
2014/09/10	19:37:00	-35.02	---	---	Gw configur ion incorrect, all traffic not removed
2014/09/23	15:27:00	-34.02	-34.02	0.00	
2014/10/17	15:40:00	-34.02	-34.02	0.00	
2014/10/23	14:12:00	-34.02	-34.02	0.00	
2015/03/12	17:30:00	-34.02	-34.02	0.00	
2015/06/08	18:51:00	-34.02	-34.02	0.00	
2015/07/29	11:28:00	-34.02	-34.02	0.00	
2015/09/25	20:06:00	-34.02	-34.02	0.00	
2016/01/13	14:02:00	-34.02	-34.02	0.00	
2016/03/16	22:27:00	-34.02	-34.02	0.00	
2016/06/09	15:26:00	-34.02	-34.02	0.00	
2016/07/01	16:08:00	-34.02	-34.02	0.00	
2016/08/24	19:40:00	-34.02	-34.02	0.00	
2016/09/23	18:25:00	-34.02	-34.02	0.00	
2016/11/21	19:44:00	-34.02	-34.02	0.00	
2017/02/14	20:47:00	-34.02	-34.02	0.00	
2017/04/06	13:34:00	-34.02	-34.02	0.00	No noise floor rise detected
2017/06/02	15:12:00	-34.02	-33.01	1.01	First detection of a 1 dB noise rise
2017/06/20	16:53:00	-34.02	-33.01	1.01	Indicates a 1 dB noise rise.
2018/03/23	15:53:00	-34.02	-33.01	1.01	Indicates a 1 dB noise rise.
2018/04/01	12:41:00	-34.02	-33.01	1.01	Indicates a 1 dB noise rise.

M083 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)



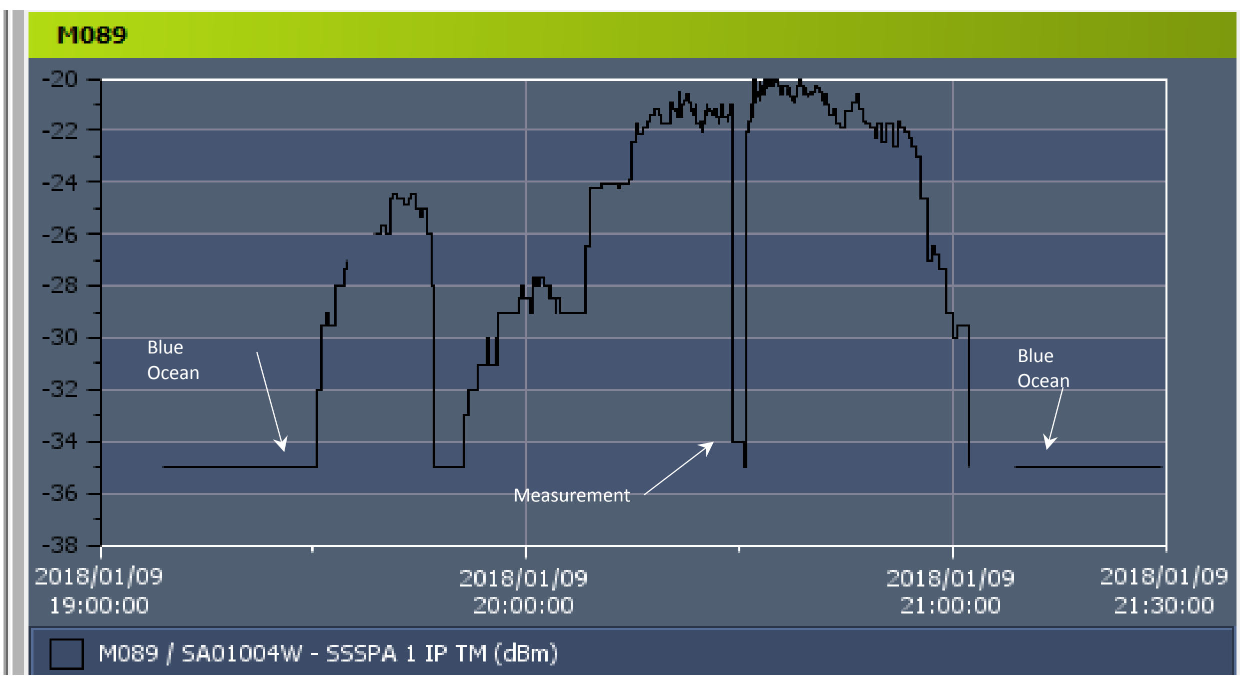


M089 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M089 - RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/30	14:44:00	-35.02	-35.02	0.00	No noise rise detected
2014/07/22	17:31:00	-35.02	-35.02	0.00	
2014/08/13	18:13:00	-35.02	-35.02	0.00	
2014/10/09	20:02:00	-35.02	-35.02	0.00	
2014/10/28	22:27:00	-35.02	-35.02	0.00	
2015/01/16	17:39:00	-35.02	-35.02	0.00	
2015/02/17	15:55:00	-35.02	-35.02	0.00	
2015/06/04	11:35:00	-35.02	-35.02	0.00	
2015/07/07	19:15:00	-35.02	-35.02	0.00	
2015/08/26	13:07:00	-35.02	-35.02	0.00	
2015/09/29	21:32:00	-35.02	-35.02	0.00	
2015/11/19	14:10:00	-35.02	-35.02	0.00	
2016/01/14	23:16:00	-35.02	-35.02	0.00	
2016/04/07	17:30:00	-35.02	-35.02	0.00	
2016/06/14	23:41:00	-35.02	-35.02	0.00	
2016/07/29	17:47:00	-35.02	-35.02	0.00	
2016/10/19	20:33:00	-35.02	-35.02	0.00	
2017/01/16	20:37:00	-35.02	-35.02	0.00	
2017/03/14	22:29:00	-35.02	-35.02	0.00	
2017/05/08	14:08:00	-35.02	-35.02	0.00	No noise rise detected
2017/06/28	17:24:00	-35.02	-35.02	0.00	No noise rise detected
2017/09/28	23:48:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise
2017/12/15	19:29:00	-35.02	-35.02	0.00	Toggling between dB and 1 dB noise rise
2018/01/09	20:29:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise
2018/01/18	17:15:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise
2018/01/23*	08:59:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise
2018/03/05	22:45:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise
2018/03/28	16:08:00	-35.02	-34.03	0.99	Current measurements indicate a 1 dB noise rise

* Night-time Measurement

M089 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)

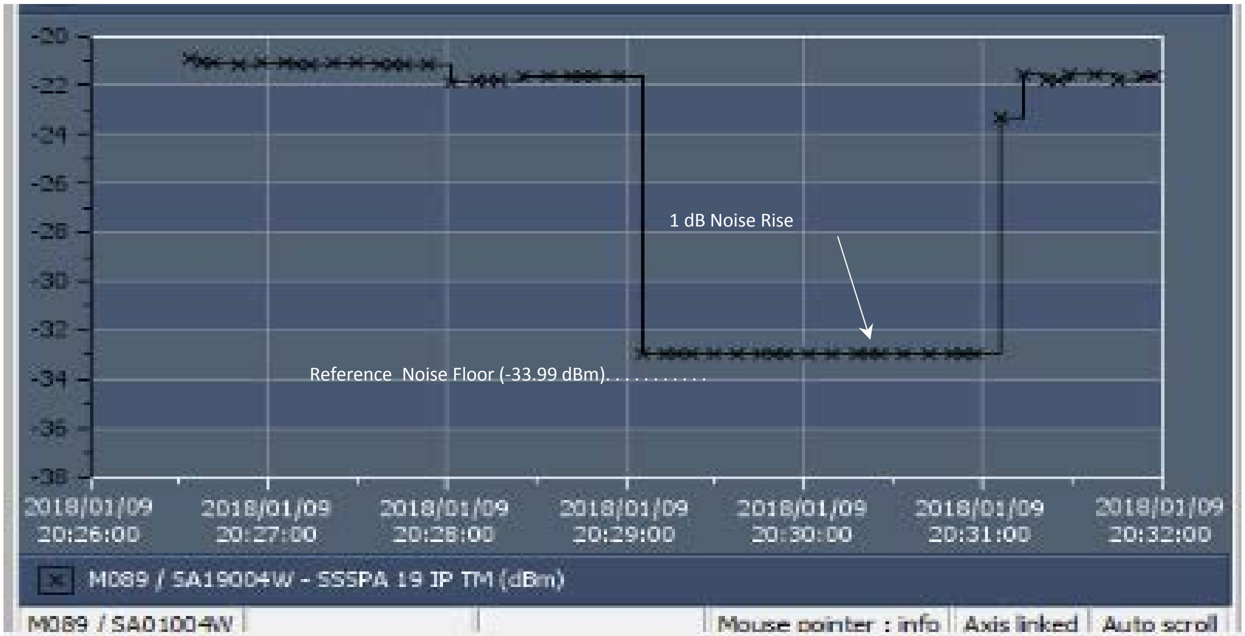


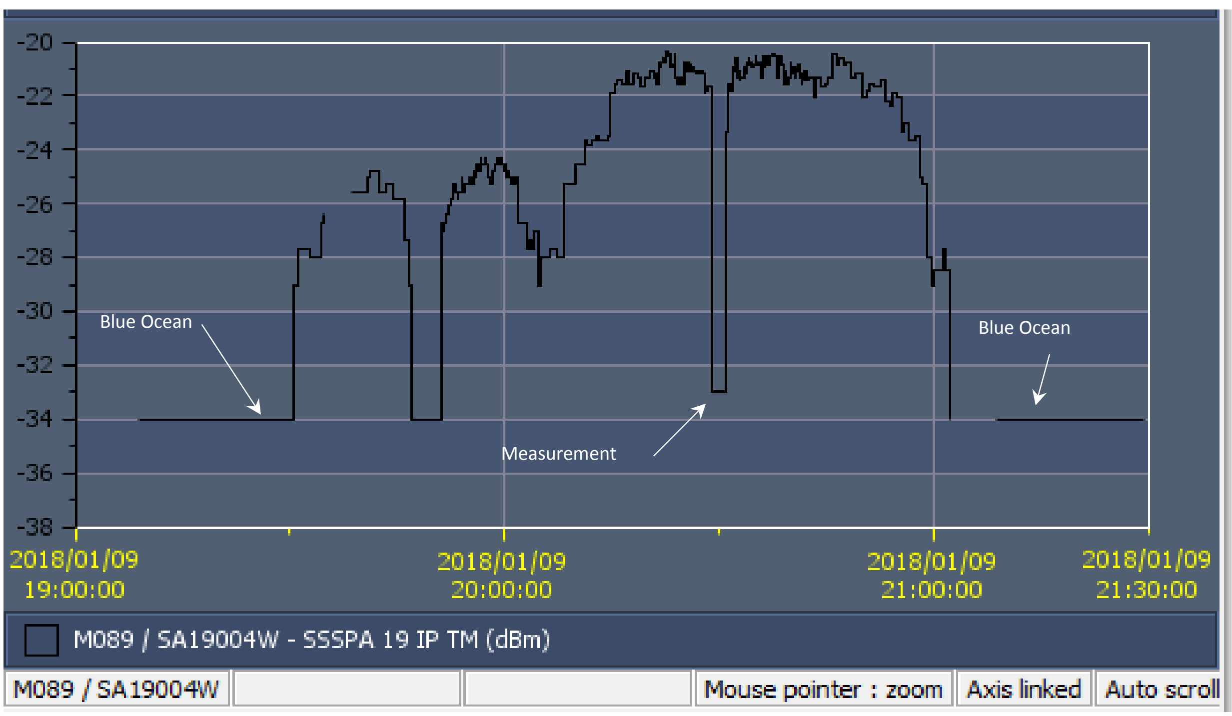
M089 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M089 - LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/30	14:44:00	-33.99	-33.99	0.00	No noise rise detected
2014/07/22	17:31:00	-33.99	-33.99	0.00	
2014/08/13	18:13:00	-33.99	-33.99	0.00	
2014/10/09	20:02:00	-33.99	-33.99	0.00	
2014/10/28	22:27:00	-33.99	-33.99	0.00	
2015/01/16	17:39:00	-33.99	-33.99	0.00	
2015/02/17	15:55:00	-33.99	-33.99	0.00	
2015/06/04	11:35:00	-33.99	-33.99	0.00	
2015/07/07	19:15:00	-33.99	-33.99	0.00	
2015/08/26	13:07:00	-33.99	-33.99	0.00	
2015/09/29	21:32:00	-33.99	-33.99	0.00	
2015/11/19	14:10:00	-33.99	-33.99	0.00	
2016/01/14	23:16:00	-33.99	-33.99	0.00	
2016/04/07	17:30:00	-33.99	-33.99	0.00	
2016/06/14	23:41:00	-33.99	-33.99	0.00	
2016/07/29	17:47:00	-33.99	-33.99	0.00	
2016/10/19	20:33:00	-33.99	-33.99	0.00	
2017/01/16	20:37:00	-33.99	-33.99	0.00	
2017/03/14	22:29:00	-33.99	-33.99	0.00	
2017/05/08	14:08:00	-33.99	-33.99	0.00	
2017/06/28	17:24:00	-33.99	-33.99	0.00	
2017/09/28	23:48:00	-33.99	-33.99	0.00	
2017/12/15	19:29:00	-33.99	-33.99	0.00	No noise rise detected
2018/01/09	20:29:00	-33.99	-33.00	0.99	Current measurements indicate a 1 dB noise rise
2018/01/18	17:15:00	-33.99	-33.00	0.99	Current measurements indicate a 1 dB noise rise
2018/01/23*	08:59:00	-33.99	-33.00	0.99	Current measurements indicate a 1 dB noise rise
2018/03/05	22:45:00	-33.99	-33.99	0.00	Toggling between 0 dB and 1 dB noise rise
2018/03/28	16:08:00	-33.99	-33.00	0.99	Toggling between 0 dB and 1 dB noise rise

* Night-time Measurement

M089 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)

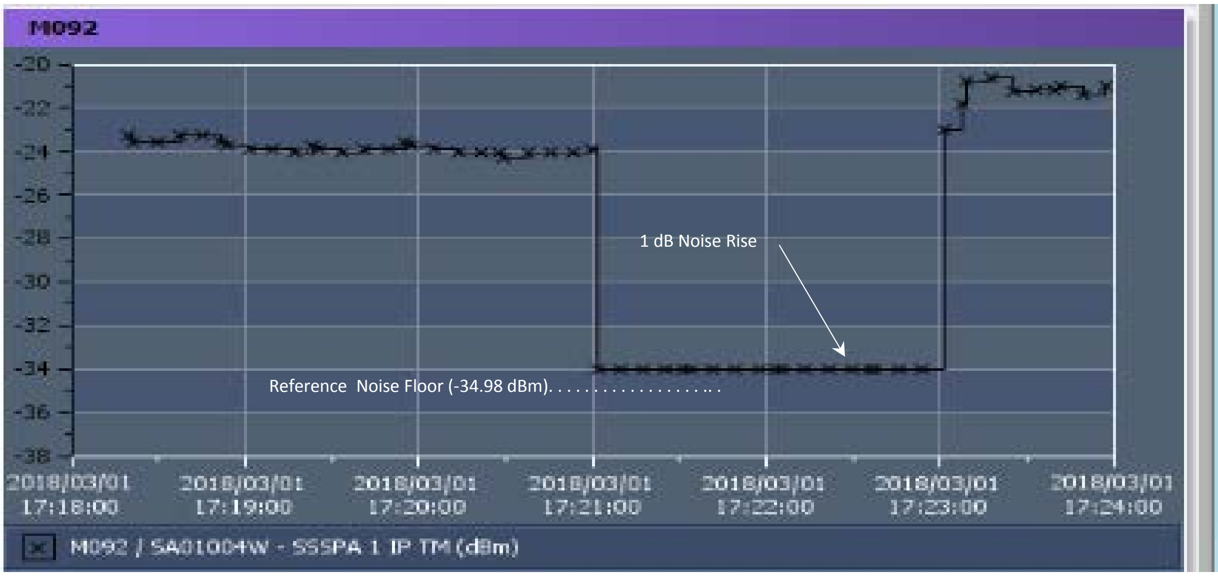


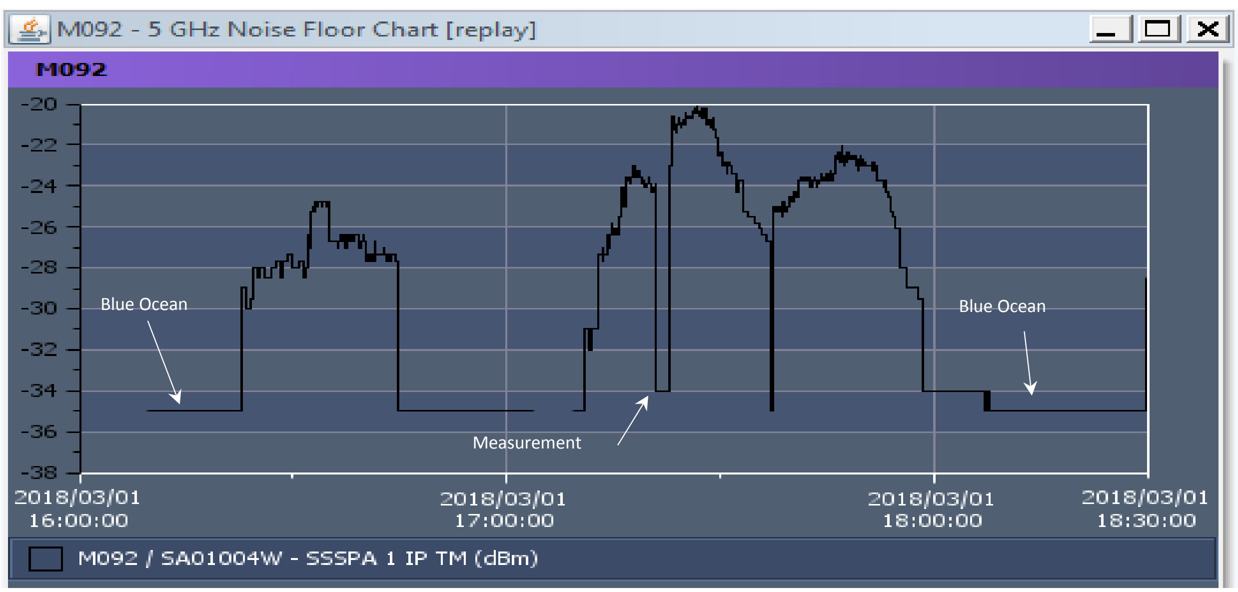


M092 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M092 - RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/06/25	18:47:00	-34.98	-34.98	0.00	No noise rise detected
2014/07/21	18:30:00	-34.98	-34.98	0.00	
2014/09/12	21:17:00	-34.98	-34.98	0.00	
2014/09/30	16:54:00	-34.98	-34.98	0.00	
2014/10/22	17:36:00	-34.98	-34.98	0.00	
2015/03/17	19:28:00	-34.98	-34.98	0.00	
2015/05/06	13:20:00	-34.98	-34.98	0.00	
2015/07/02	21:12:00	-34.98	-34.98	0.00	
2015/09/01	22:02:00	-34.98	-34.98	0.00	
2015/10/21	15:54:00	-34.98	-34.98	0.00	
2015/12/21	16:45:00	-34.98	-34.98	0.00	
2016/03/11	18:46:00	-34.97	---	---	Gw configuration incorrect, all traffic not removed
2016/04/12	17:03:00	-34.98	-34.98	0.00	
2016/06/10	18:21:00	-34.98	-34.98	0.00	
2016/08/26	21:21:00	-34.98	-34.98	0.00	
2016/09/21	15:00:00	-34.98	-34.98	0.00	
2016/11/22	22:39:00	-34.98	-34.98	0.00	No noise rise detected
2017/03/08	17:34:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/04/05	16:48:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/06/01	18:37:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/06/16	22:01:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/06/29	17:51:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/09/28	17:26:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2017/11/17	21:57:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2018/01/04	16:20:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2018/02/08	23:28:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise
2018/03/01	17:21:00	-34.98	-34.03	0.95	Current measurements indicate a 1 dB noise rise

M092 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)

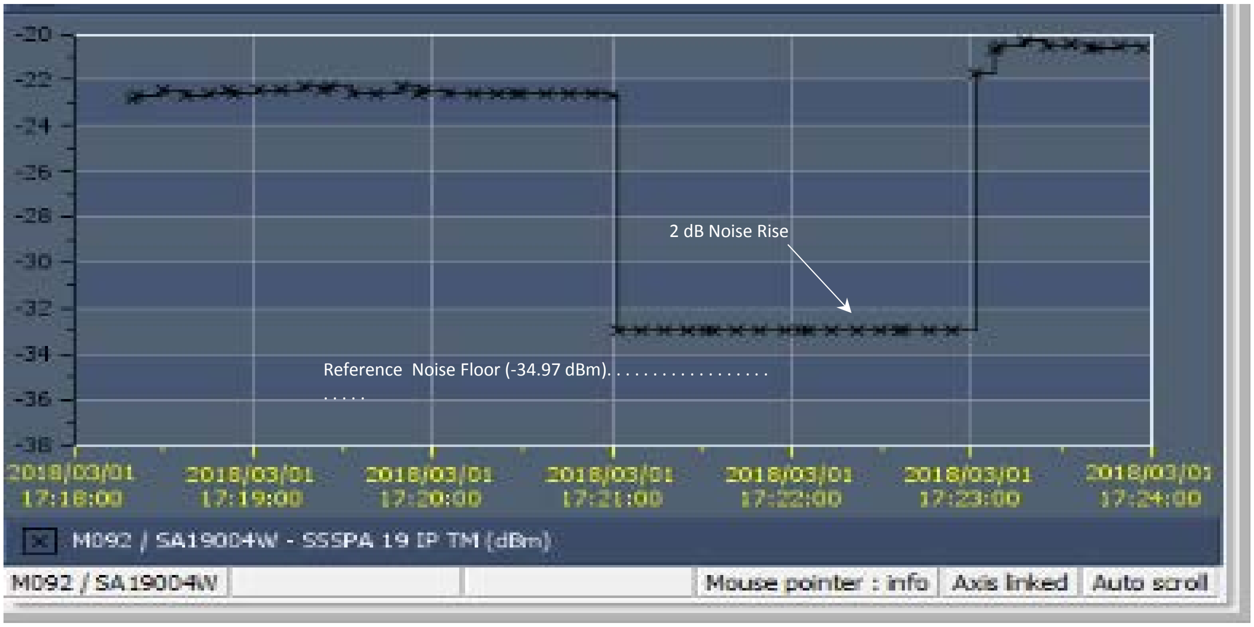


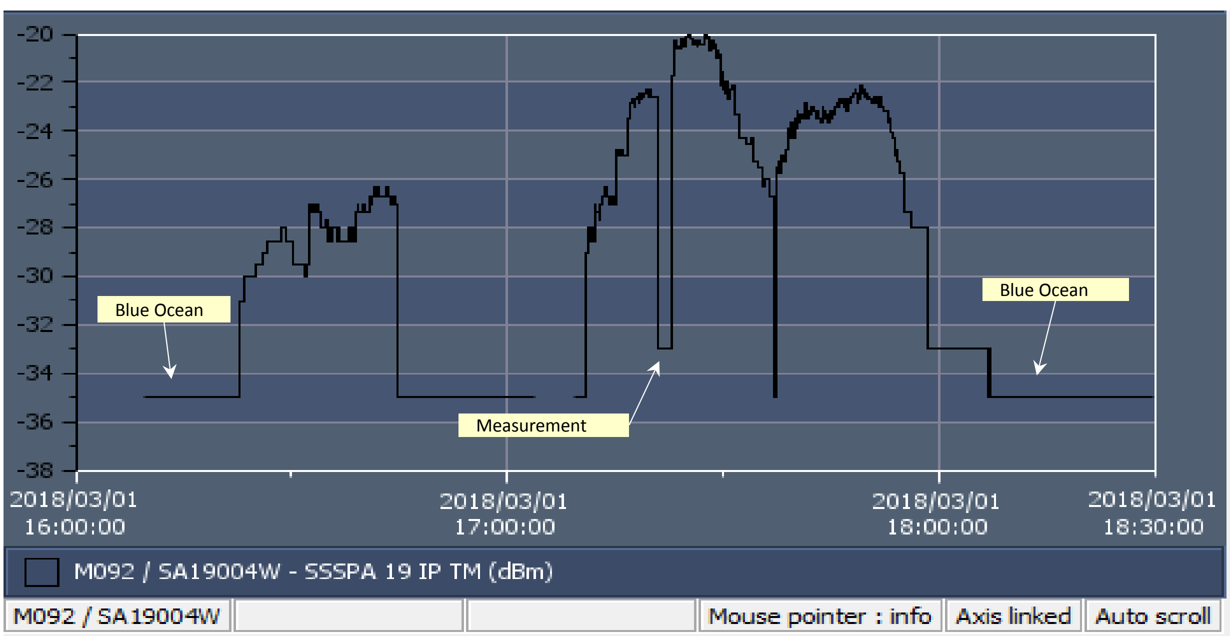


M092 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M092 - LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/06/25	18:47:00	-34.97	-34.97	0.00	No noise rise detected
2014/07/21	18:30:00	-34.97	-34.97	0.00	
2014/09/12	21:17:00	-34.97	-34.97	0.00	
2014/09/30	16:54:00	-34.97	-34.97	0.00	
2014/10/22	17:36:00	-34.97	-34.97	0.00	
2015/03/17	19:28:00	-34.97	-34.97	0.00	
2015/05/06	13:20:00	-34.97	-34.97	0.00	
2015/07/02	21:12:00	-34.97	-34.97	0.00	
2015/09/01	22:02:00	-34.97	-34.97	0.00	
2015/10/21	15:54:00	-34.97	-34.97	0.00	
2015/12/21	16:45:00	-34.97	-34.97	0.00	
2016/03/11	18:46:00	-34.97	---	---	Gw configuration incorrect, all traffic not removed
2016/04/12	17:03:00	-34.97	-34.97	0.00	
2016/06/10	18:21:00	-34.97	-34.97	0.00	
2016/08/26	21:21:00	-34.97	-34.97	0.00	
2016/09/21	15:00:00	-34.97	-34.97	0.00	
2016/11/22	22:39:00	-34.97	-34.97	0.00	No noise rise detected
2017/03/08	17:34:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/04/05	16:48:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/06/01	18:37:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/06/16	22:01:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/06/29	17:51:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/09/28	17:26:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2017/11/17	21:57:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2018/01/04	16:20:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2018/02/08	23:28:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise
2018/03/01	17:21:00	-34.97	-33.01	1.96	Current measurements indicate a 1 dB noise rise

M092 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)



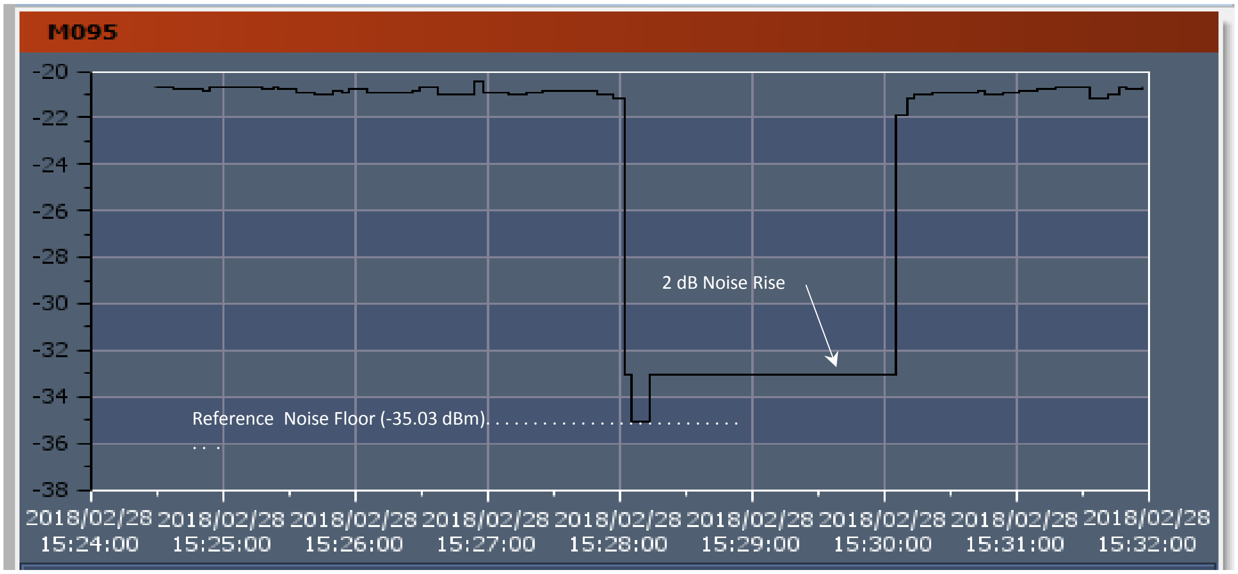


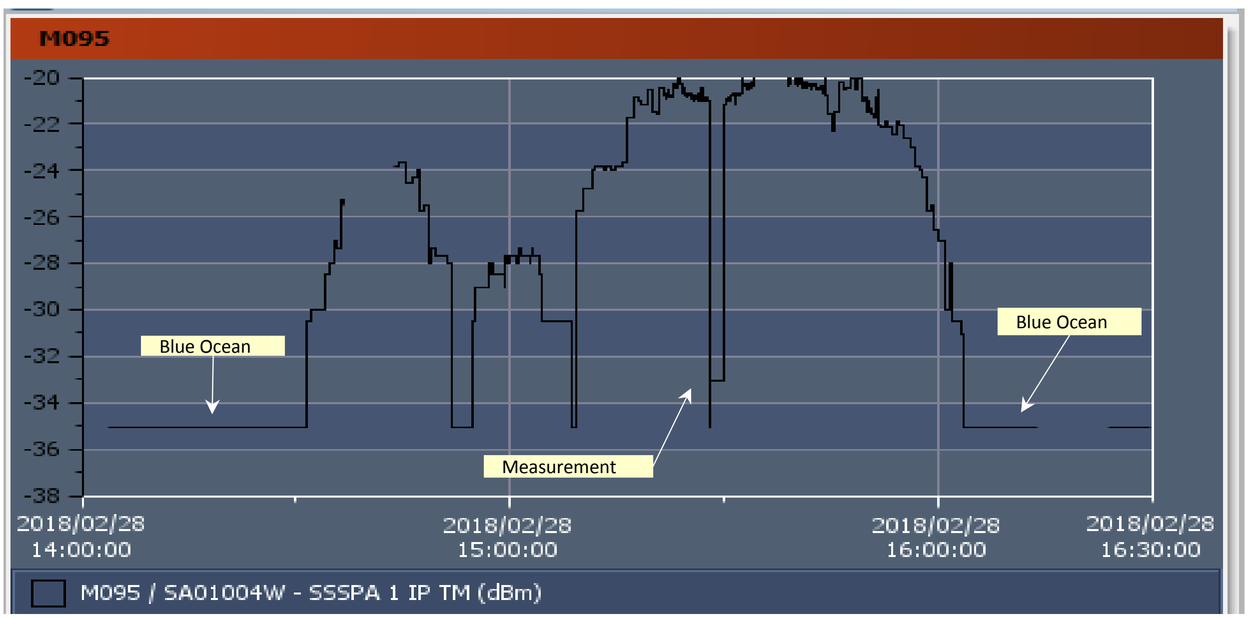
M095 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M095- RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/29	16:53:00	-35.03	-35.03	0.00	No noise rise detected
2014/06/20	17:35:00	-35.03	-35.03	0.00	
2014/06/30	15:09:00	-35.03	-35.03	0.00	
2014/08/19	19:40:00	-35.03	-35.03	0.00	
2014/09/05	14:31:00	-35.03	-35.03	0.00	
2014/09/25	15:42:00	-35.03	-35.03	0.00	
2015/02/12	19:03:00	-35.03	-35.03	0.00	
2015/05/12	19:07:00	-35.03	-35.03	0.00	
2015/07/01	12:59:00	-35.03	-35.03	0.00	
2015/08/28	21:36:00	-35.03	-35.03	0.00	
2015/10/26	22:55:00	-35.03	-35.03	0.00	
2015/12/16	15:34:00	-35.03	-35.03	0.00	
2016/02/11	17:22:00	-35.03	-35.03	0.00	
2016/03/14	15:37:00	-35.03	-35.03	0.00	
2016/05/06	18:24:00	-35.03	-35.03	0.00	
2016/08/01	18:58:00	-35.03	-35.03	0.00	
2016/10/24	21:15:00	-35.03	-35.03	0.00	
2017/01/17	22:18:00	-35.03	-35.03	0.00	
2017/02/09	15:41:00	-35.03	-35.03	0.00	No noise rise detected
2017/05/03	17:29:00	-35.03	-33.04	1.99	First detection of 2dB noise rise
2017/06/06	15:16:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/06/14	13:19:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/07/27	18:32:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/8/28	16:48:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/10/24	18:37:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/11/15	19:18:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2018/01/09	21:34:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2018/01/17	19:39:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2018/02/28*	09:25:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2018/02/28	15:28:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2017/03/01*	08:11:00	-35.03	---	---	Gateway malfunction, all traffic not removed
2018/03/03*	07:41:00	-35.03	-33.04	1.99	Current measurements indicate a 2 dB noise rise
2018/03/05*	07:12:00	-35.03	-33.04	1.99	Small indication of 3 dB Rise

* Night-time measurements

M095 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)



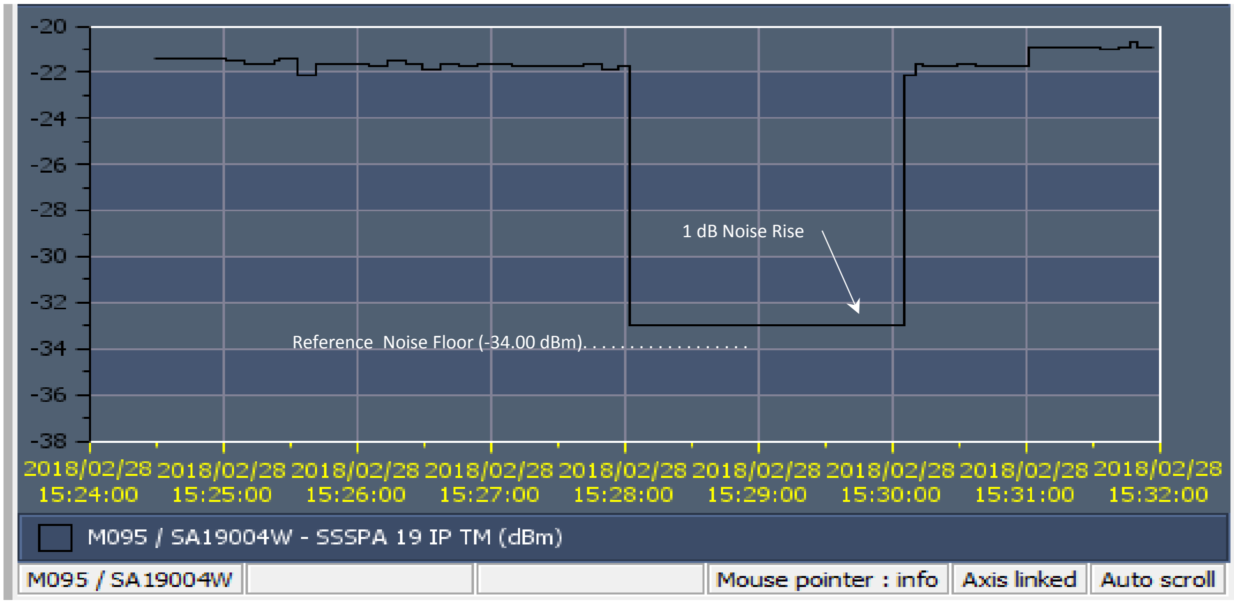


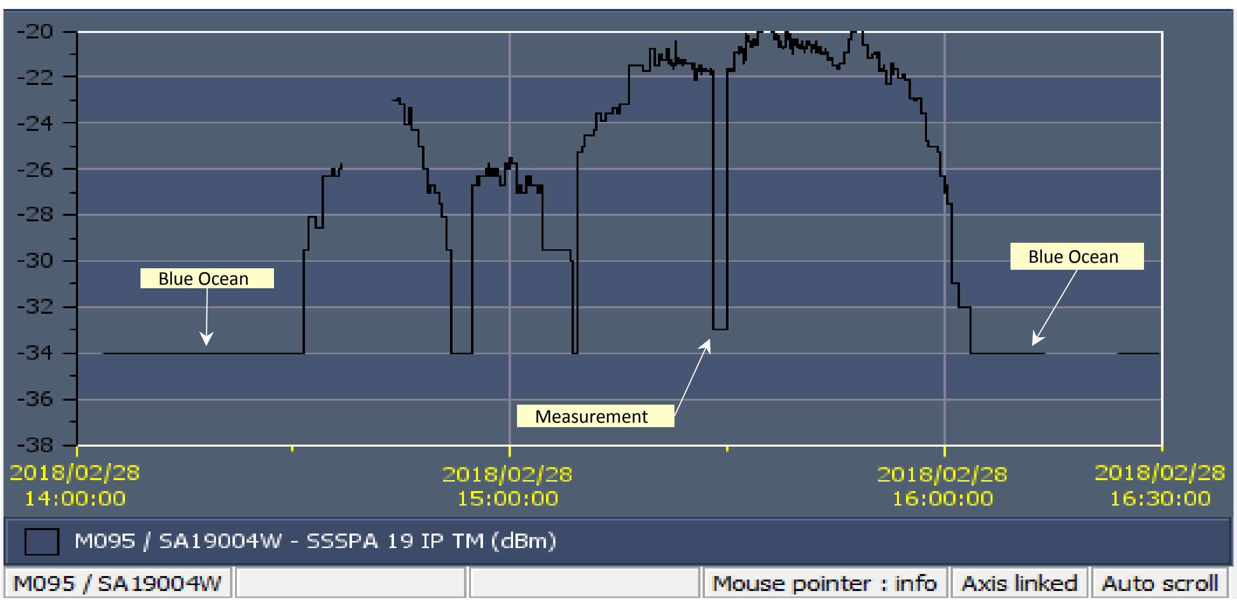
M095 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M095 - LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/25	16:53:00	-34.00	-34.00	0.00	No noise rise detected
2014/05/29	17:35:00	-34.00	-34.00	0.00	
2014/06/20	15:09:00	-34.00	-34.00	0.00	
2014/06/30	19:40:00	-34.00	-34.00	0.00	
2014/08/19	14:31:00	-34.00	-34.00	0.00	
2014/09/05	15:42:00	-34.00	-34.00	0.00	
2015/02/12	19:03:00	-34.00	-34.00	0.00	
2015/05/12	19:07:00	-34.00	-34.00	0.00	
2015/07/01	12:59:00	-34.00	-34.00	0.00	
2015/08/28	21:36:00	-34.00	-34.00	0.00	
2015/10/26	22:55:00	-34.00	-34.00	0.00	
2015/12/16	15:34:00	-34.00	-34.00	0.00	
2016/02/11	17:22:00	-34.00	-34.00	0.00	
2016/03/14	15:37:00	-34.00	-34.00	0.00	
2016/05/06	18:24:00	-34.00	-34.00	0.00	
2016/08/01	18:58:00	-34.00	-34.00	0.00	
2016/10/24	21:15:00	-34.00	-34.00	0.00	
2017/01/17	22:18:00	-34.00	-34.00	0.00	No noise rise detected
2017/02/09	15:41:00	-34.00	-32.99	1.01	First detection of 1 dB noise rise
2017/05/03	17:29:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/06/06	15:16:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/06/14	13:19:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/07/27	18:32:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/8/28	16:48:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/10/24	18:37:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/11/15	19:18:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2018/01/09	21:34:00	-34.00	-32.99	1.01	Toggling between 0 dB and 1 dB noise rise
2018/01/17	19:39:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2018/02/28*	09:25:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2018/02/28	15:28:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2017/03/01*	08:11:00	-34.00	---	---	Gateway malfunction, all traffic not removed
2018/03/03*	07:41:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise
2018/03/05*	07:12:00	-34.00	-32.99	1.01	Current measurements indicate a 1 dB noise rise

* Night-time measurements

M095 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)



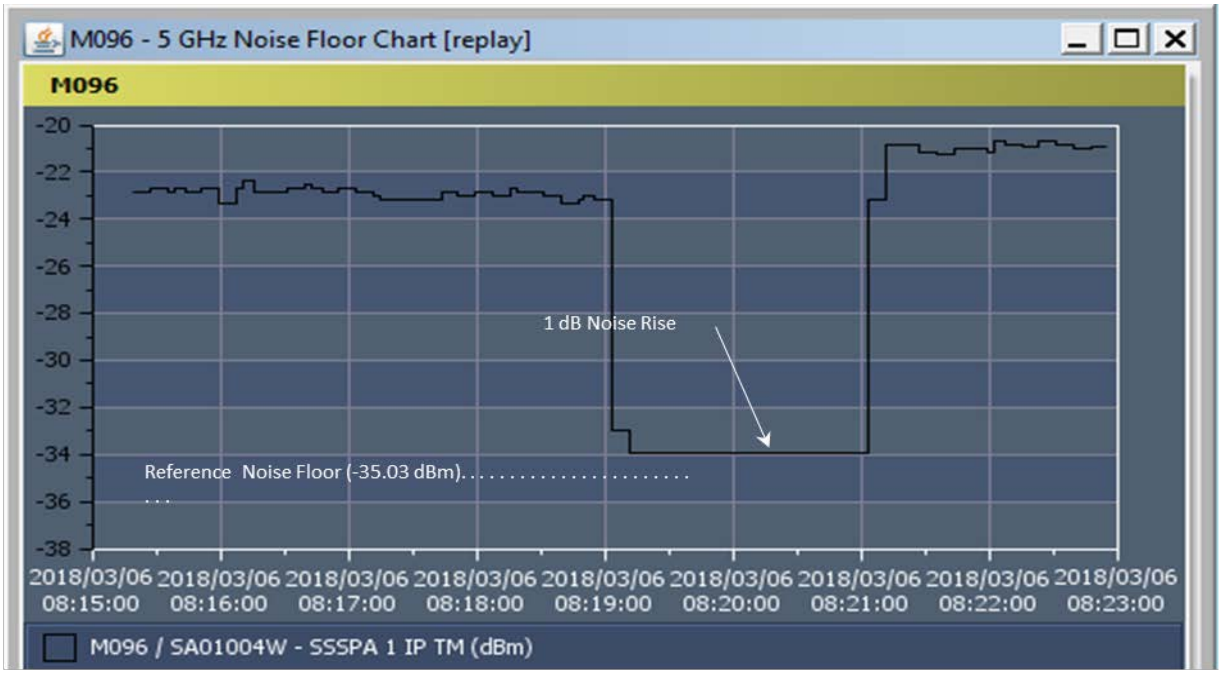


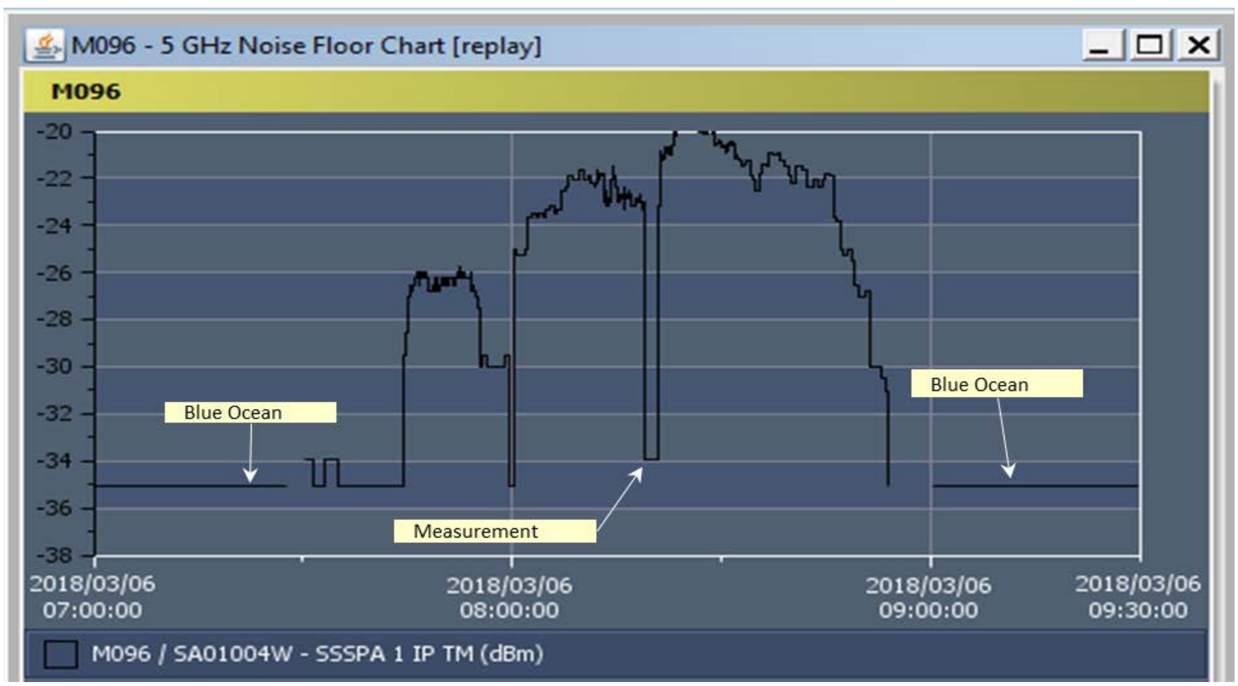
M096 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (1.0 dB, +/- 0.5 dB)

M096 - RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/15	14:30:00	-35.03	-35.03	0.00	No noise rise detected
2014/08/01	18:15:00	-35.03	-35.03	0.00	
2014/10/13	22:12:00	-35.03	-35.03	0.00	
2014/10/27	18:48:00	-35.03	-35.03	0.00	
2015/01/20	19:50:00	-35.03	-35.03	0.00	
2015/03/11	13:44:00	-35.03	---	---	Gw configuration incorrect, all traffic not removed
2015/06/03	14:00:00	-35.03	-35.03	0.00	
2015/09/28	23:56:00	-35.03	-35.03	0.00	
2015/11/23	16:21:00	-35.03	-35.03	0.00	
2016/01/15	19:07:00	-35.03	-35.03	0.00	
2016/04/11	19:40:00	-35.03	-35.03	0.00	
2016/08/30	13:08:00	-35.03	-35.03	0.00	
2016/09/26	22:15:00	-35.03	-35.03	0.00	
2016/11/17	15:38:00	-35.03	-35.03	0.00	
2017/02/08	17:10:00	-35.03	-35.03	0.00	No noise rise detected
2017/04/10	18:24:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/06/30	20:25:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/07/31	17:56:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/08/24	12:05:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/09/27	20:29:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/10/18	14:22:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2017/12/17	22:30:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/01/07	16:22:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/01/20	20:17:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/02/08*	08:35:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/02/10*	08:06:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/02/12*	07:37:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/03/02*	09:17:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise
2018/03/06*	08:19:00	-35.03	-33.96	1.07	Current measurements indicate a 1 dB noise rise

* Night-time measurement

M096 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (1.0 dB, +/- 0.5 dB)

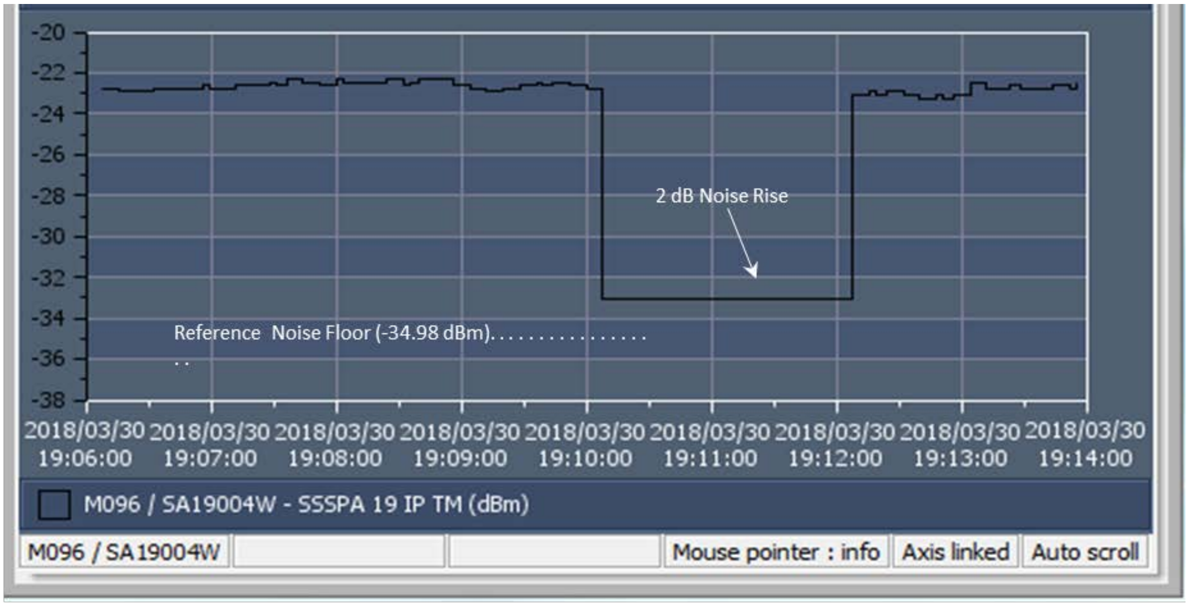


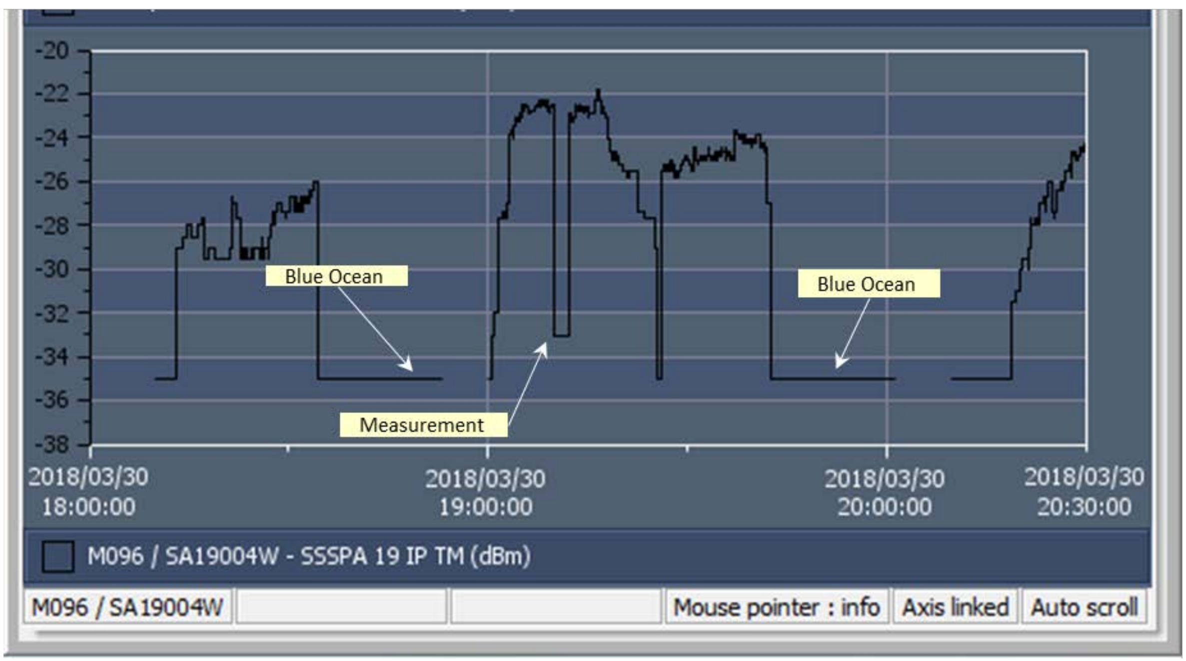


M096 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M096 - LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise dB)	Comments
2014/05/15	14:30:00	-34.98	-34.98	0.00	No noise rise detected
2014/08/01	18:15:00	-34.98	-34.98	0.00	
2014/10/13	22:12:00	-34.98	-34.98	0.00	
2014/10/27	18:48:00	-34.98	-34.98	0.00	
2015/01/20	19:50:00	-34.98	-34.98	0.00	
2015/03/11	13:44:00	-34.98	---	---	Gw configurat n incorrect, all traffic not removed
2015/06/03	14:00:00	-34.98	-34.98	0.00	
2015/09/28	23:56:00	-34.98	-34.98	0.00	
2015/11/23	16:21:00	-34.98	-34.98	0.00	
2016/01/15	19:07:00	-34.98	-34.98	0.00	
2016/04/11	19:40:00	-34.98	-34.98	0.00	
2016/08/30	13:08:00	-34.98	-34.98	0.00	
2016/09/26	22:15:00	-34.98	-34.98	0.00	
2016/11/17	15:38:00	-34.98	-34.98	0.00	
2017/02/08	17:10:00	-34.98	-34.98	0.00	
2017/04/10	18:24:00	-34.98	-34.98	0.00	No noise rise detected
2017/06/30	20:25:00	-34.98	-34.98	0.00	No noise rise detected
2018/03/18	22:05:00	-34.98	-33.02	1.96	Current measurements indicate a 2 dB noise rise
2018/03/30	19:10:00	-34.98	-33.02	1.96	Current measurements indicate a 2 dB noise rise

M096 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)

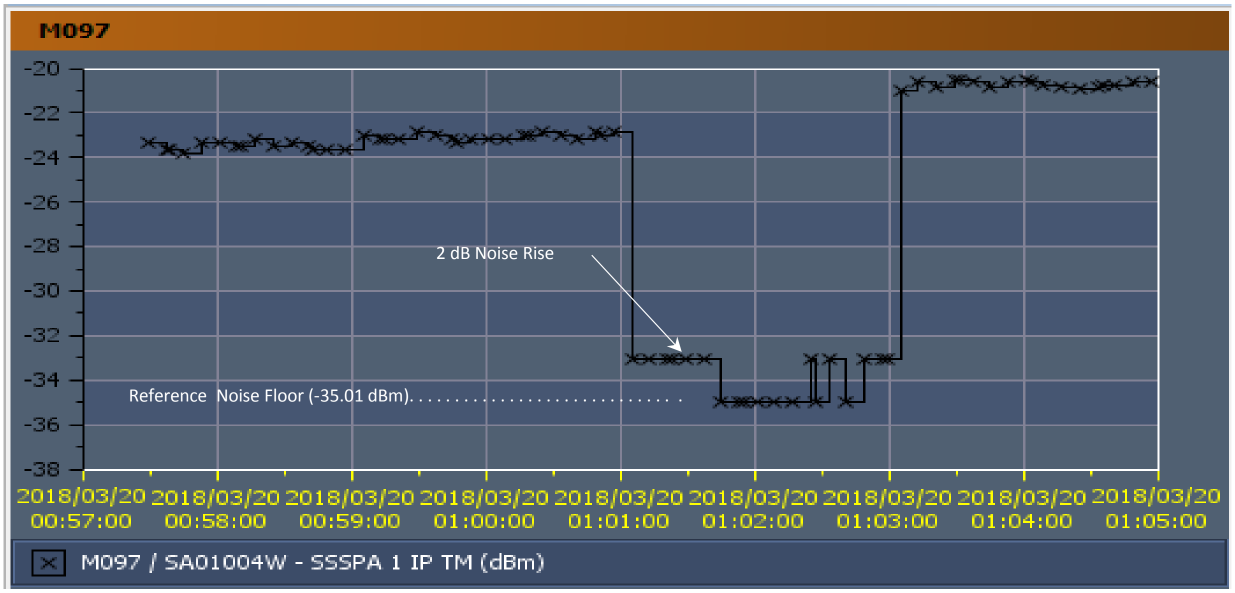


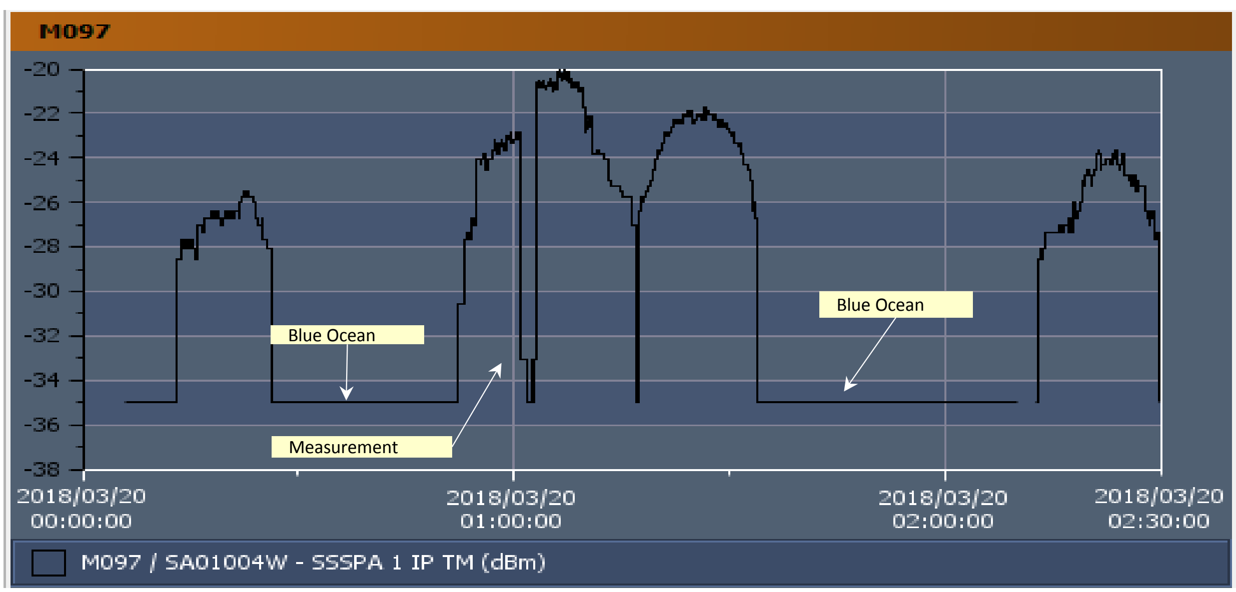


M097 - RHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M097-RHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/05/22	16:26:00	-35.01	-35.01	0.00	No noise floor rise detected
2014/06/13	17:08:00	-35.01	-35.01	0.00	
2014/08/05	19:55:00	-35.01	-35.01	0.00	
2014/08/29	14:04:00	-35.01	-35.01	0.00	
2014/09/19	14:01:00	-35.01	-35.01	0.00	
2015/02/13	16:39:00	-35.01	-35.01	0.00	
2015/05/07	18:10:00	-35.01	-35.01	0.00	
2015/08/04	18:14:00	-35.01	-35.01	0.00	
2015/10/22	20:44:00	-35.01	-35.01	0.00	
2015/12/17	13:09:00	-35.01	-35.01	0.00	
2016/01/19	20:48:00	-35.01	-35.01	0.00	
2016/03/09	14:41:00	-35.01	-35.01	0.00	
2016/05/09	15:31:00	-35.01	-35.01	0.00	
2016/06/08	14:16:00	-35.01	-35.01	0.00	
2016/07/27	18:01:00	-35.01	-35.01	0.00	
2016/10/20	19:04:00	-35.01	-35.01	0.00	
2017/01/11	20:36:00	-35.01	-35.01	0.00	
2017/03/10	12:31:00	-35.01	-35.01	0.00	
2017/05/04	14:44:00	-35.01	-35.01	0.00	
2018/02/07	18:04:00	-35.01	-35.01	0.00	No noise floor rise detected
2018/03/20	01:01:00	-35.01	-33.02	1.99	First detection of a 2 dB noise rise
2018/03/31	22:06:00	-35.01	-33.02	1.99	Currently indicating a 2 dB noise rise.

M097 - RHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)



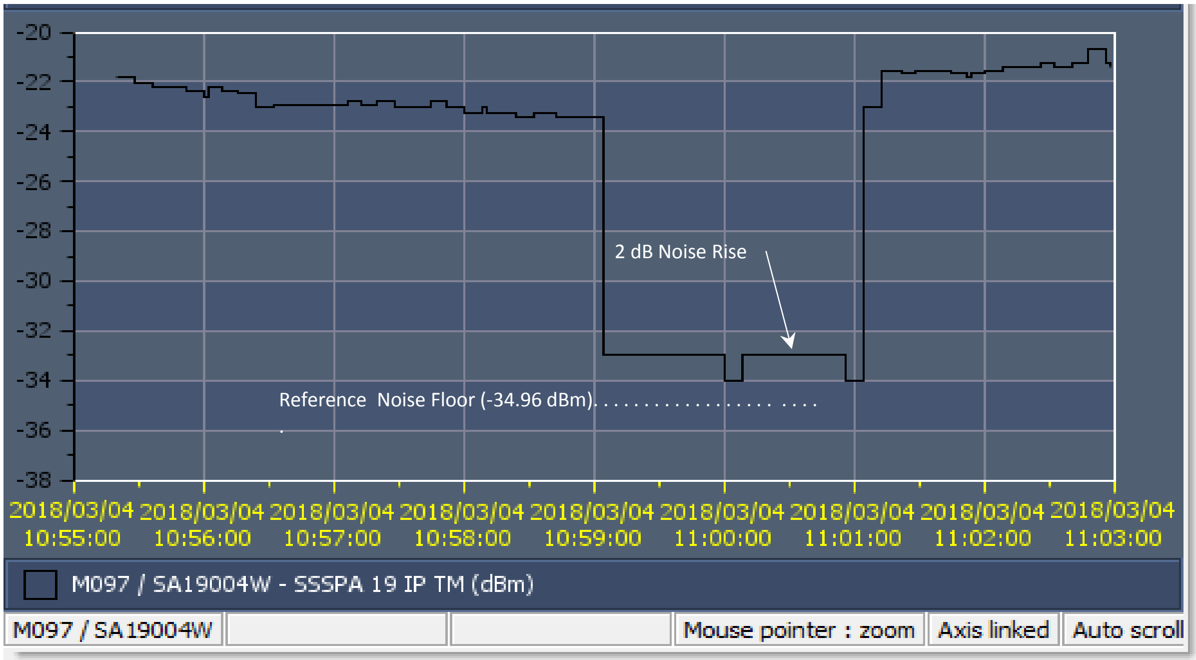


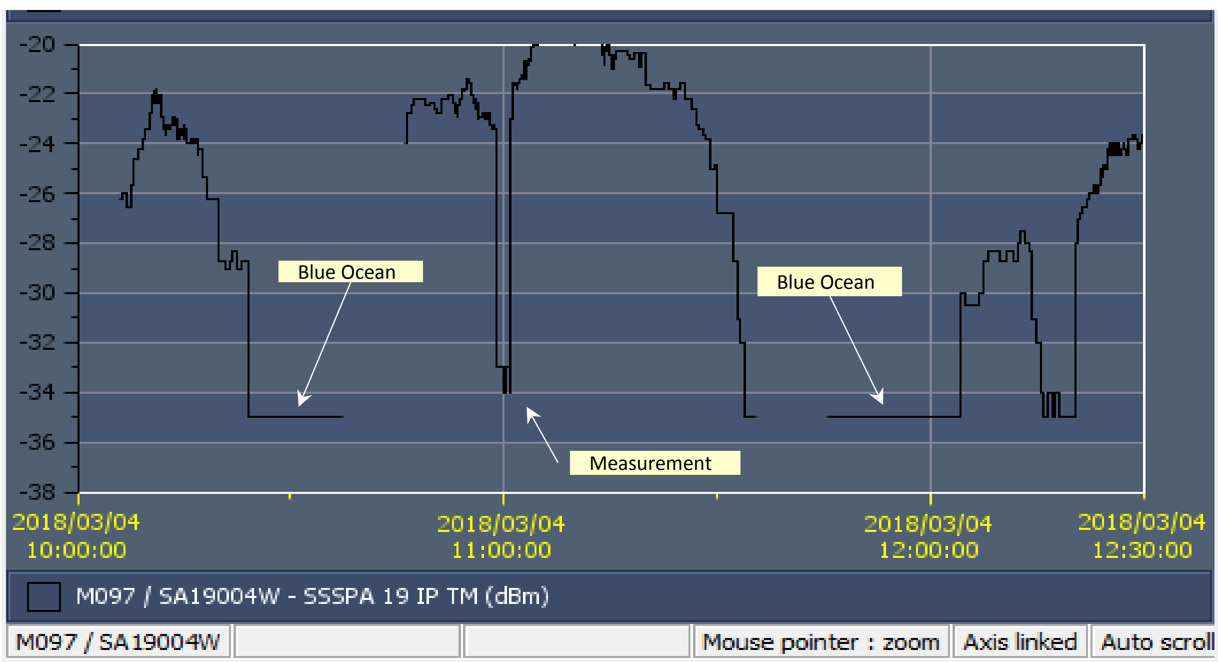
M097 - LHCP Transponder - 5 GHz Noise Floor Measurement Timeline (2.0 dB, +/- 0.5 dB)

M097-LHCP Measurement Date	Measurement Start Time (GMT)	May 2014 Reference Noise Level (dBm)	SSPA Input Level Measurement (dBm)	Noise Rise (dB)	Comments
2014/05/22	16:26:00	-34.96	-34.96	0.00	No noise floor rise detected
2014/06/13	17:08:00	-34.96	-34.96	0.00	
2014/08/05	19:55:00	-34.96	-34.96	0.00	
2014/08/29	14:04:00	-34.96	-34.96	0.00	
2014/09/19	14:01:00	-34.96	-34.96	0.00	
2015/02/13	16:39:00	-34.96	-34.96	0.00	
2015/05/07	18:10:00	-34.96	-34.96	0.00	
2015/08/04	18:14:00	-34.96	-34.96	0.00	
2015/10/22	20:44:00	-34.96	-34.96	0.00	
2015/12/17	13:09:00	-34.96	-34.96	0.00	
2016/01/19	20:48:00	-34.96	-34.96	0.00	
2016/03/09	14:41:00	-34.96	-34.96	0.00	
2016/05/09	15:31:00	-34.96	-34.96	0.00	
2016/06/08	14:16:00	-34.96	-34.96	0.00	
2016/07/27	18:01:00	-34.96	-34.96	0.00	
2016/10/20	19:04:00	-34.96	-34.96	0.00	
2017/01/11	20:36:00	-34.96	-34.96	0.00	No noise floor rise detected
2017/03/10	12:31:00	-34.96	-33.99	0.97	First detection of a 1 dB noise rise
2017/05/04	14:44:00	-34.96	-33.99	0.97	Indicates a 1 dB noise rise
2017/08/01	14:48:00	-34.96	-33.00	1.96	First detection of a 2 dB noise rise
2017/08/25	15:00:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2017/10/03	21:11:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2017/10/22	23:38:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2017/11/20	15:33:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2018/01/06	19:47:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2018/02/07	18:04:00	-34.96	-33.99	0.97	Toggling between 1 dB and 2 dB noise rise
2018/02/12*	09:48:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise
2018/03/04*	10:59:00	-34.96	-33.00	1.96	Indicates a 2 dB noise rise

* Night-time measurements

M097 - LHCP Transponder Daytime 5 GHz Noise Floor Measurement Charts (2.0 dB, +/- 0.5 dB)





Appendix B

Roberson and Associates, LLC
Technology and Management Consultants

Analysis and Impact of Noise Rise in Feeder Uplinks of Globalstar Mobile Satellite Network

Prepared for Globalstar Inc., by:

Roberson and Associates, LLC
Chicago, Illinois

Principal Contributors:

Alan Wilson
Kenneth J. Zdunek
Roger Peterson

Date: May 21, 2018

Analysis and Impact of Noise Rise on Feeder Uplinks of Globalstar Mobile Satellite Network

Summary

In 2014 the Federal Communications Commission issued a Report and Order allowing unlimited outdoor deployment of unlicensed Wi-Fi access points ("APs") in the U.S. "U-NII-1" band, spectrum that includes IEEE 802.11ac channels at 5170-5250 MHz. These channels overlap the licensed 5096-5250 MHz fixed feeder uplink band for Globalstar, Inc.'s ("Globalstar's") Mobile Satellite Service (MSS). Beginning in February, 2017, despite FCC access point requirements limiting vertical emissions, Globalstar began observing a rising noise floor in the feeder uplink spectrum for its satellites operating over the U.S. In June, 2017 Globalstar began to measure consistently a 1 ± 0.5 dB noise level rise at 5096-5250 MHz, and in October 2017 began regularly observing 2 ± 0.5 dB noise level increases compared to 2014 levels. The noise floor rise is highly likely to be caused by the aggregated emissions of outdoor U-NII-1 access points deployed across the United States, since no other emission sources have been identified that could produce this effect. These noise rise levels are produced by 1.8 ± 0.8 dB and 3.3 ± 0.7 dB noise rises, respectively, in the U-NII-1 band at 5170-5250 MHz where IEEE 802.11ac based Wi-Fi networks operate. Significantly, no increase in the noise is measured by Globalstar satellites when in view of oceans, or in view of Europe or Australia where outdoor access points are not permitted.

Technical analysis shows that a 1 dB noise rise at Globalstar satellites operating over the U.S is consistent with the deployment of approximately one million outdoor U-NII-1 access points operating at an average transmitter busy-period duty cycle of 10%. Other combinations of likely duty cycles and numbers of outdoor U-NII-1 access points can produce the same noise rise. For example, 250,000 APs operating at an average duty cycle of 40%, or 500,000 APs operating at an average duty cycle of 20%, produce the same noise rise. The analysis assumes the access points comply with FCC transmit power and antenna gain regulations.

Based on cable industry filings with the FCC that indicate that there were approximately 10 million U-NII-1 total indoor and outdoor access points deployed by cable operators in the U.S as of July 2017, the 1 dB noise rise observed by Globalstar can be attributed to cable industry outdoor deployments of 250,000 to one million access points, depending on their average duty cycle. In all likelihood, the number of outdoor U-NII-1 access points in the U.S. today is much higher than the maximum 250,000 outdoor U-NII-1 access points and 1 dB noise rise projected in 2014 by the cable industry in its 2014 FCC filing.

Technical analysis also shows that the current level of noise rise due to Wi-Fi interference is causing Globalstar user capacity and satellite power amplifier capacity degradations, as well as user coverage and call quality degradation. In October 2017, Globalstar's call-handling capacity in an area equivalent to more than half the area of the contiguous US was likely reduced by as much as

6%. The analysis shows that if (i) the number of outdoor U-NII-1 access points in the U.S. increases at industry projected rates of 35-43% per year and (ii) average access point duty cycles reach 20% due to an increased number of users and/or greater data per user, then by 2022 Globalstar will suffer a degradation to its MSS traffic-handling capacity as great as 35%, along with further voice call quality degradation and data transmission impairments. This degradation is based on the relationship between noise rise in Globalstar's feeder uplink spectrum and the concomitant degradation to Globalstar's satellite-to-handset downlink, due to the "bent pipe" nature of Globalstar's satellite communication architecture.

Degradation due to interference will be most acutely felt by life-critical users of Globalstar's satellites during large scale disaster events such as Hurricane Katrina in 2005. During that event, Globalstar satellites operated at 78% of capacity in specific spot beams. If a similar event occurs in 2021, when a noise rise of 5 dB as measured by Globalstar's satellites in 5096-5250 MHz is expected to occur, Globalstar satellites would not be able to handle that level of traffic. User voice and data traffic above that level will cause an increase in failed and dropped calls and a reduced satellite service area for all users. Notably, due to the increase in voice and data users on Globalstar's network since 2005, traffic demand during disasters can be expected to be higher in 2021.

Currently, there is no method for limiting the number of outdoor U-NII-1 access points operating within the continental U.S., a region that represents only a portion of the geographic area (with a 7800 km diameter) within which U-NII-1 access points contribute to aggregate interference to Globalstar's feeder uplink. In addition to the outdoor U-NII-1 access points deployed by commercial operators, other outdoor U-NII-1 access point operations could exacerbate this aggregate interference in the future. The majority of "self-provisioned" consumer-grade access points available in the U.S. through online or "brick and mortar" retailers – including APs capable of operating outdoors - support U-NII-1 operation. In addition, U.S. cellular operators indicate that, based on recent field trials of LTE-U (LTE-unlicensed) and LAA (License Assisted Access) for supplemental downlink operations in 5150-5250 MHz, they plan to widely deploy LTE systems at 5 GHz (including outdoor systems) in 2018. The existence of unlicensed LTE operations in U-NII-1 was not even foreseen, much less considered, in the 2014 Report and Order.

Significantly, the degradation to Globalstar's mobile satellite operations is not limited to the U.S. but is manifested in areas of the satellite downlink coverage footprint which extends into Canada, Mexico, the Caribbean, and Central and South America when the satellite is operating over the United States. Given that such MSS communications normally involve safety of life situations, the consequences of such degraded services, especially during large-scale natural or man-made disasters, could be devastating. Accordingly, the Commission should take action to protect Globalstar's licensed MSS feeder link spectrum at 5096-5250 MHz and its MSS service downlink to customers in the 2.4 GHz band from harmful aggregate interference from unlicensed, outdoor U-NII-1 systems.

Table of Contents

List of Figures

List of Tables

1. Introduction

This document provides an analysis of the noise rise measured by Globalstar in the fixed feeder uplinks of its satellites at 5096-5250 MHz over the United States in 2017 and 2018. The potential sources of the increased noise are investigated, with the conclusion that it is highly likely that the primary cause of this noise rise is aggregate interference from outdoor Wi-Fi access points operating in the U-NII-1 band at 5170-5250 MHz.[1] The document compares the expected interference resulting from the authorization of outdoor U-NII-1 access points in the U.S. to the actual measured interference to Globalstar feeder uplinks, as measured at Globalstar's satellites. The document analyzes the impact of this noise rise on Globalstar operations and assesses the current and potential future degradation to Globalstar's MSS capacity and functionality resulting from this harmful aggregate interference from outdoor U-NII-1 access point deployments.

2. Globalstar Overview and Feeder Uplink Interference Scenario

2.1 Globalstar Architecture

Globalstar currently operates a full-duplex global mobile satellite service using a constellation of non-geostationary low earth orbit satellites.[2] The Globalstar system architecture includes earth station "gateways" which interconnect with terrestrial networks and communicate to the satellites using a 5096-5250 MHz uplink and a 7 GHz downlink. For communications to the mobile user handheld devices, transponders on the satellite convert 5 GHz uplink signals conveying user information on multiple CDMA channels to 2483.5-2500 MHz for retransmission to the mobile user devices. Signals from the mobile devices are transmitted to the satellites in CDMA channels in the frequency band 1610-1618.725 MHz. The satellite translates the CDMA channels conveying user information from the mobile devices to the 7 GHz band for retransmission to the earth station gateway.

2.2 Globalstar Feeder Uplink Interference Scenario

The interference generated by outdoor U-NII-1 access points to the gateway-to-satellite feeder uplink is illustrated in Figure 1. Unlicensed wireless access points using terrestrial wireless local

[1] Globalstar's satellite feeder uplink antennas are authorized by the FCC to operate at 5096-5250 MHz.
[2] Information provided by Globalstar, Inc., and *The Globalstar System, Applied Microwave and Wireless*, Summer 1995.

area network (WLAN) protocols such as the IEEE 802.11ac[3], are required to operate on a co-channel, non-interference basis in the frequency region 5170-5250 MHz and communicate with wireless LAN client (user) devices. Since the transmitted power of client devices is typically much less than the access point power level, the access points are expected to be the primary source of aggregate interference to the satellite's feeder uplinks. Emissions from the access points intended for the wireless LAN client devices are also radiated in the direction of the satellites, and degrade the uplink signals sent from the gateway to the satellite by adding undesired interference power to the received signal at the satellite. These access point emissions thus cause a measurable rise in the uplink noise-plus-interference level at the satellite. The degraded received signal at the satellite, consisting of the desired Globalstar uplink signal plus noise and the unlicensed device interference, is then translated to the 2500 MHz downlink, thereby ultimately degrading the received signal at the Globalstar client device. The diameter of the service area for subscribers on the downlink at 2483.5-2500 MHz is 5800 km, which is illustrated as a pink circle in Figure 2 for one representative satellite location centered over North America. The service area is further divided into 16 spot beam coverage areas, as shown by the white lines in Figure 2.

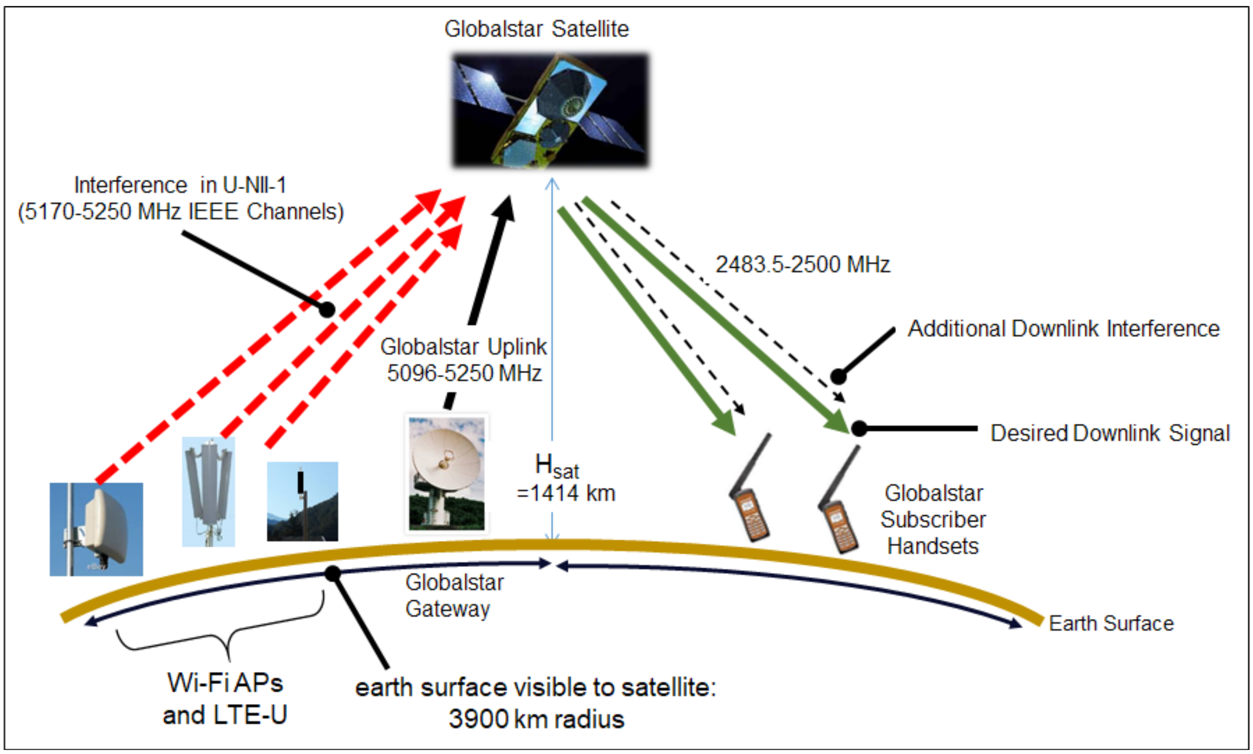


Figure 1: Globalstar Interference Scenario

While the service area of a single satellite has a diameter of approximately 5800 km on the earth's surface, Wi-Fi access points within a satellite viewing "footprint" with a 7800 km diameter on the earth's surface contribute to the aggregate interference on the satellite's feeder uplinks. This

[3] *See* Rohde and Schwartz, *IEEE TGac Draft Amendment v1.1 [16], August 2011,* and *802.11ac Technology Introduction White Paper,* accessed at http://www.rohde-schwarz.com/en/applications/802.11ac-technology-introduction-application-note_56280-15417.html

footprint is shown in Figure 2 with a yellow circle. The transmissions from all outdoor U-NII-1 access points within this footprint create an aggregate level of measurable interference at the satellite receiver that is not limited to the geography of the gateways. This is an aggregate interference problem at the satellite receiver that manifests itself in a degraded downlink signal to the Globalstar user devices. As shown in Figure 29 in Appendix C, which illustrates the Globalstar satellite downlink-to-handheld coverage footprints, uplink interference created by outdoor U-NII-1 access points operating in the United States would have an adverse effect on the Globalstar system communications originating and terminating in Mexico, Canada, the Caribbean, and Central and South America, violating the conditions of ITU-R **RR No. 4.4**. Thus, Globalstar satellite communications originating and terminating in other countries are impacted. Additionally, the deployment of any outdoor U-NII-1 devices at higher power levels in foreign countries would affect satellite services provided within U.S. territory.

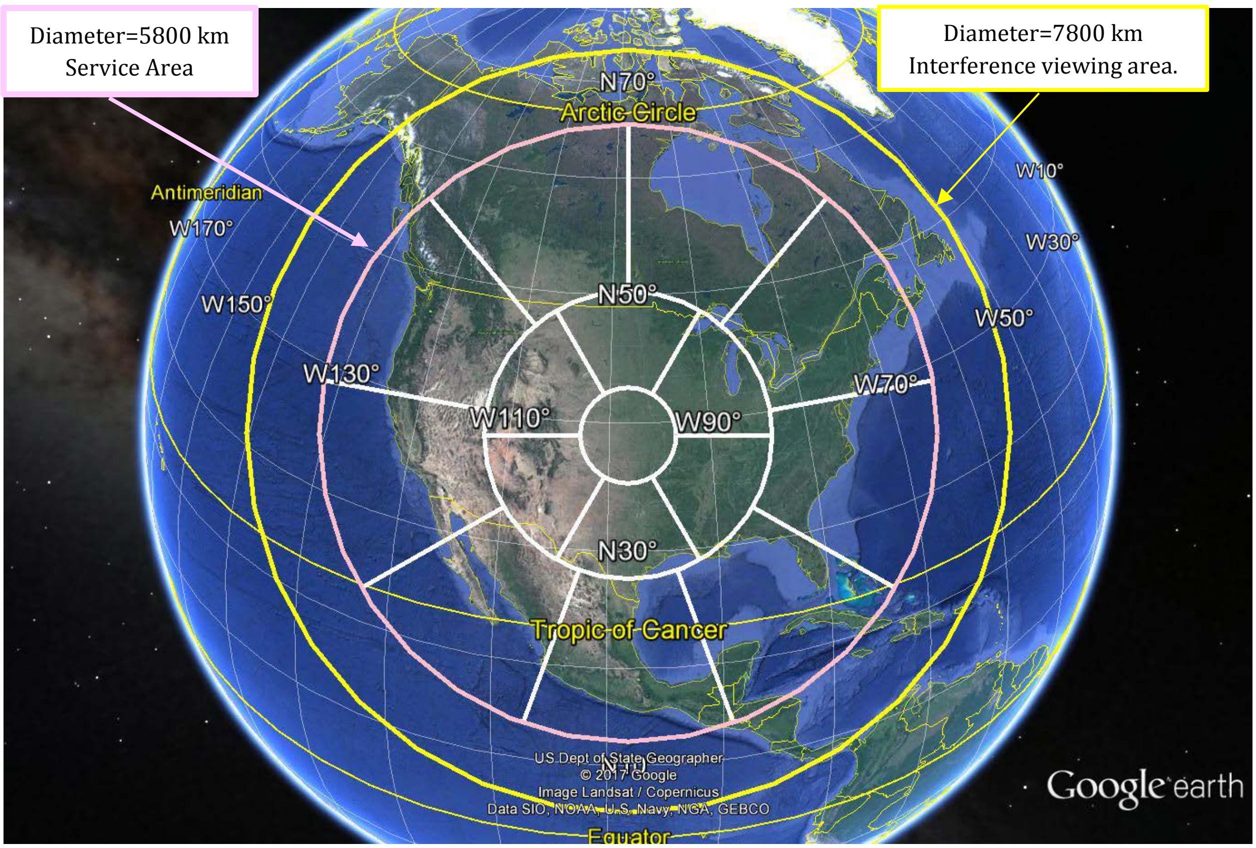


Figure 2: Globalstar Gateway Uplink Satellite Footprints for North America[4]

2.3 Globalstar and Wi-Fi Access Point Frequency Plans

Figure 3 illustrates the interference scenario between unlicensed devices operating at 5170-5250 MHz and the Globalstar feeder uplink.[5] Globalstar's feeder uplink at 5096-5250 MHz consists of

[4] Provided by Globalstar, Inc.
[5] Provided by Globalstar, Inc.

separate signals with left and right hand circular polarization, each with a full set of 104, 1.23 MHz CDMA channels. The desired signal at 5170-5250 MHz, which is a portion of the total satellite uplink, consists of 53 1.23 MHz CDMA channels transmitted in 4 groups of 13, plus 1 additional CDMA channel in a 5th group, in each of two polarizations. These 106 CDMA channels at 5170-5250 MHz overlap with the U.S. U-NII-1 band. (An additional 51 CDMA channels on Globalstar's feeder uplink are transmitted between 5096 and 5170 MHz.) The immediate impact of co-channel interference in the upper 53 channels is to degrade the signal-to-noise ratio on those channels. The satellite divides the uplink channels into 8 groups of channels for each polarization, which are then retransmitted in 16 separate spot beams within the service area illustrated as the pink circle in Figure 2. The spot beam coverage areas are indicated by white lines. The downlink frequency band is 16.5 MHz wide from 2483.5 to 2500 MHz, and the frequencies are the same for all of the downlink spots. Because the spots overlap, interference from the uplink is distributed over all of the downlink spots, even though the uplink channels might fall within the set of 102 channels in the lower half of the spectrum.

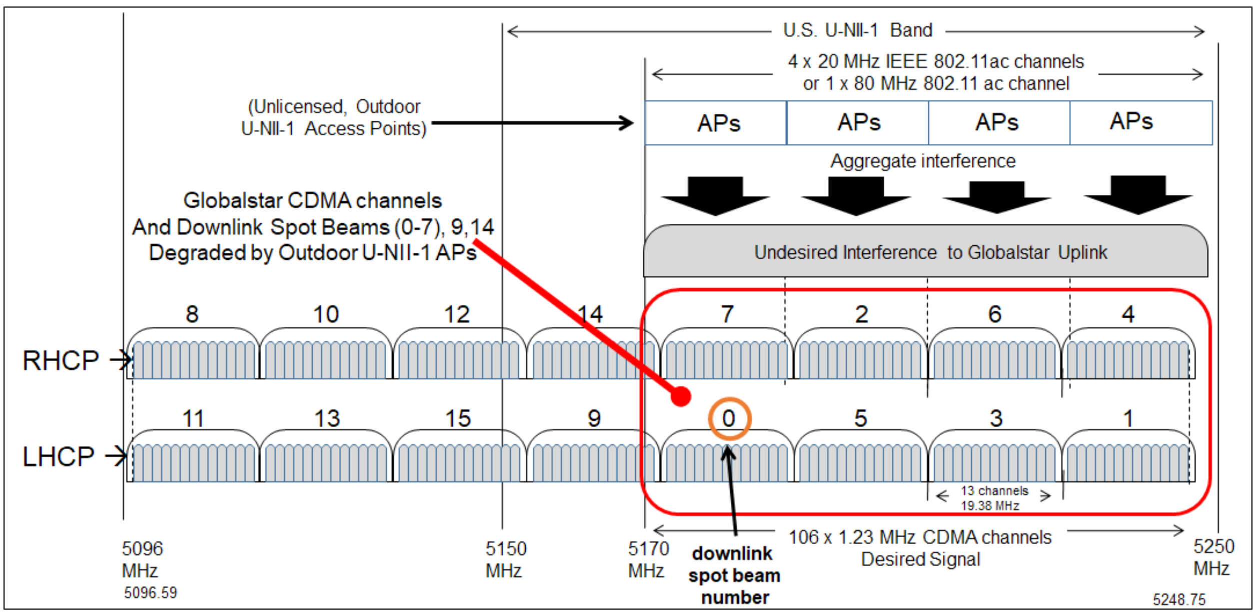


Figure 3: Globalstar Frequency Plan and U-NII-1 Band Interference Scenario

In Figure 3, the representative scenario shows the total power spectrum for a population of *N* wireless LAN access points utilizing the IEEE 802.11ac standard, each operating with a 20 MHz bandwidth within the U-NII-1 band at 5170-5250 MHz and within the receiving feeder uplink antenna footprint of the satellite. If the wireless LAN access point population is divided equally among the 4 IEEE 802.11ac channels in the U-NII-1 band, then the emissions from N/4 access points in each 20 MHz generate an aggregate level of interference at the satellite receiver with a power spectral density that is the same as the sum of the received powers of N access points at the satellite distributed over 80 MHz. Since the gateway-to-satellite uplink is transmitted in right- and left-hand circular polarizations, a total of 106 CDMA channels are affected by unlicensed access points.[6]

Satellite Downlink Spot Alignment

The Globalstar satellite downlink in the 2483.5-2500 MHz band consists of 16 spot beams numbered 0-15 arranged in 2 rings, and with a central spot as shown in Figure 4.

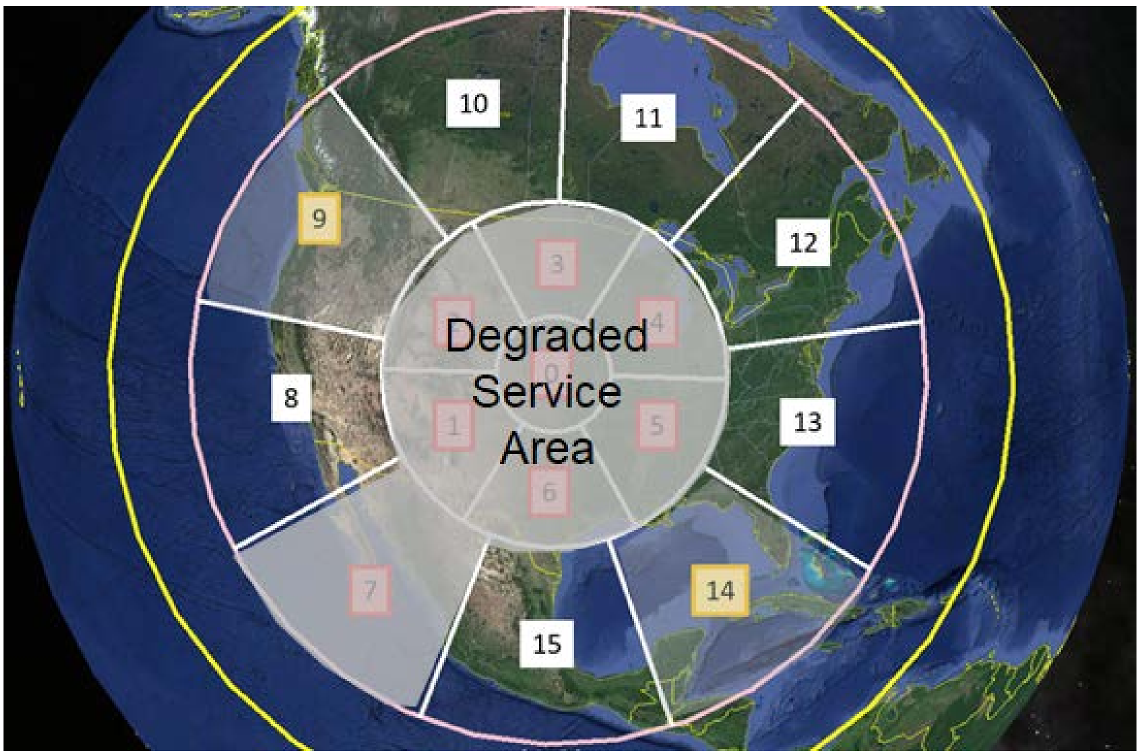


Figure 4: Satellite Downlink Spots, with Area Degraded by Uplink Interference Shaded

Each spot maps to different frequencies in Globalstar's feeder uplink in the 5096-5250 MHz band, as shown in Figure 5. There are two different transmissions in the feeder uplink, one with Right Hand Circular Polarization (RHCP) and another with Left Hand Circular Polarization (LHCP). Each

[6] The IEEE 802.11ac standard provides for access point bandwidths from 20 to 160 MHz. For an analysis of the impact of the unlicensed access points on Globalstar operations, the channel bandwidth of the access points makes no difference. For example, the aggregate interference power spectral density of 4 million access points with 80 MHz bandwidth is the same as for one million access points with 20 MHz bandwidth. If 80 MHz access points are deployed, and the total emitted power of each access point is the same as a 20 MHz bandwidth access point, then the power spectral density of each 80 MHz access point is ¼ of the power spectral density of a 20 MHz bandwidth access point. But 4 million access points in 80 MHz (4 times the number in 20 MHz) are still needed to provide coverage to a given geographic area.

of these has 8 groups of 13 CDMA channels (see details in Figure 3), with each group spanning about 18 MHz in the uplink. The numbers in each group in Figure 5 correspond to the spot numbers in the satellite downlink spots. Groups 0 through 7 correspond to the co-channel overlap with unlicensed Wi-Fi access points, and there is some additional overlap with a CDMA channel in groups 9 and 14, as is shown in Figure 3. In Figure 4 the spots 0 through 7 are shaded and they cover the central spot (0), the middle ring of 6 spots, and one spot (7) in the outer ring. Two other spots (9 and 14) in the outer ring indicated by light shading are also partially affected by co-channel interference from outdoor U-NII-1 access points.

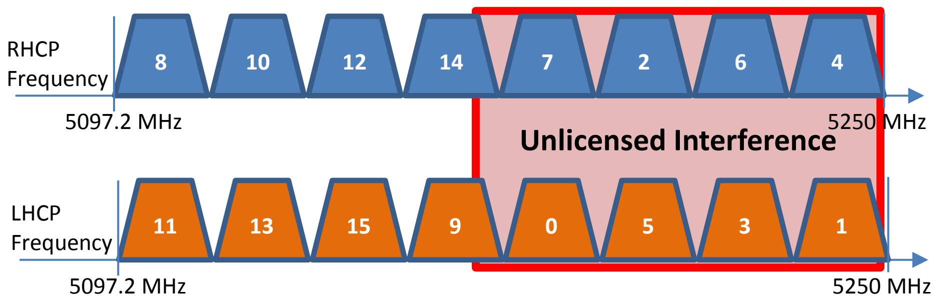


Figure 5: Feeder Uplink CDMA Groups

The earth surface area covered by the spots can be calculated from the satellite downlink antenna pattern. The results are tabulated in Table 1. The total land area for spots 0-7 adds up to 7.302 million square km. This compares with a land area of the continental US (CONUS), excluding Alaska and large bodies of water, of 7.66 million square km. So, the area of the spots affected by co-channel interference in all 13 of their CDMA channels is 95% of the CONUS land area. If we included the areas of spots 9 and 14 that are also affected by co-channel interference in one CDMA channel, then the area increases to 12.08 million square km, or 58% larger than the CONUS land area.

The Globalstar satellite constellation provides continuous service over the U.S. Since the Globalstar satellites' orbital period is 114 minutes, both the sub-satellite point and the mid-point of spot beams affected by interference, move across the earth's surface at approximately 350 km per minute. As a result, voice calls and packet data communications sessions, with average call and session durations of 2.5 and 0.3 minutes, respectively, typically originate and terminate within a single spot beam, and at most experience a single handover between adjacent spot-beams.

Table 1. Satellite Downlink Spot Beam Areas

Central Spot (0)	Middle Spots (1-6)	Outer Spots (7-15)	Area of Spots with Interference: 0-7
526 thousand km^2	731 thousand km^2	2390 thousand km^2	7302 thousand km^2

3. Noise Rise Measured by Globalstar

3.1 Example Noise Rise Measurement on Globalstar Uplink

The plot in Figure 6 below is an example of the noise-rise measurements at the Globalstar satellites as measured over North America (as described in a report prepared by Globalstar).[7] The plot on the left of Figure 6 shows the power level measured at the satellite at the input to the solid-state power amplifier (SSPA), and including noise and interference in the bandwidth at 5096-5250 MHz, versus time of day as the satellite approaches and then travels over the continental United States. The power level on the vertical axis is a measure of the signal-plus-noise and interference in the satellite uplink. The flat portions of the graph correspond to regions where the satellite is receiving no earth station signals, and are therefore measures of the noise floor at that location. The elevated "humps" correspond to the signal-plus-noise and interference when one or more earth station signals are being received by the satellite. The power received by the single satellite varies as the distance between the satellite and earth stations changes. The part of the plot in Figure 6 in the dotted-box corresponds to the portion of the orbit as the satellite traverses the continental U.S. during the daytime. The noise floor over the U.S. when the sub-satellite point is in the vicinity of Lincoln, Kansas is obtained by scheduling the satellite uplink to be out of service for a period of two minutes centered on that location, during which time the noise floor can be measured at the satellite. In the expanded view of the graph on the right, the noise floor as measured outside the U.S. is compared to the noise floor measured over Lincoln, Kansas, approximately in the geographic center of the United States. A noise floor difference, or noise rise, over the U.S. of 1 ± 0.5 dB is readily observed.[8] There is no rise in the noise floor measured when the satellite is in view of ocean areas only, and not receiving any feeder uplink transmissions. Significantly, there is also no noise rise measured by Globalstar's satellites while in view of Europe, a densely populated region but an area where outdoor Wi-Fi (Radio-LAN) are not permitted. Measurements in progress for satellites over Australia (seven transponders on five satellites out of a total of eight to be measured) indicate no observed noise rise. At present,[9] in contrast, Globalstar is measuring noise rise levels of 2 ± 0.5 dB on 6 out of a total of 8 satellites being monitored while they are over the U.S. during daytime periods. Where Globalstar has measured a 2 ± 0.5 dB noise rise during the day, it has found only a 1 ± 0.5 dB noise rise at those satellites during nighttime periods.[10] A lower nighttime noise rise is consistent with the expectation that there would be lower access point data traffic, and therefore

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[7] Globalstar 5 GHz C-Band Noise Floor Measurement Description and Current Results, May 21, 2018 ("*Globalstar Noise Floor Measurement Report*").

[8] The 0.5 dB uncertainty in the noise rise measurement is due to the resolution of the A/D converter at the output of the noise power detector and the initial calibration procedure, as described in the *Globalstar Noise Floor Measurement Report* at page 15.

[9] May 3, 2018.

[10] Globalstar's nighttime measurements have occurred from 1 AM to 5 AM ET, with the sub-satellite point at the middle of the two minute measurement period within 350 km of Lincoln, Kansas.

lower transmission duty cycles, during nighttime hours. Details of the noise rise measurements are contained in the Globalstar Noise Floor Measurement Report.[11]

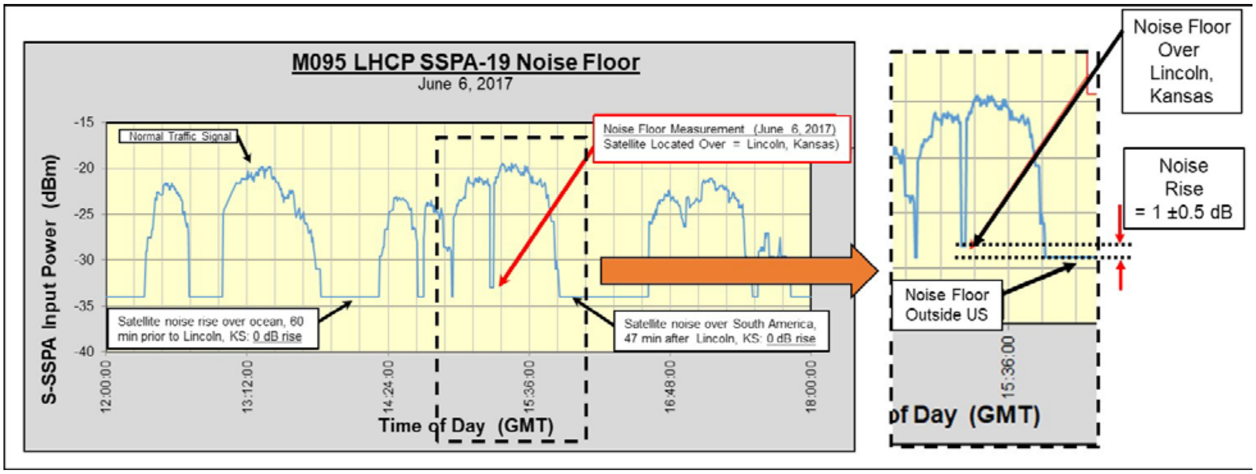

Figure 6: Power at Input to S-Band Amplifiers, Illustrating Noise Rise Over U.S.

3.2 Evidence That Satellite Noise Rise is Due to Wi-Fi Interference in 5170-5250 MHz

In order to provide evidence that the noise rise observed in the Globalstar's feeder uplink spectrum is due to terrestrial Wi-Fi access point emissions at 5170-5250 MHz and not caused by terrestrial emissions in the 5096-5170 MHz portion of this feeder uplink, a drive test was conducted in the suburban area of Chicago, Illinois. In this test, an RF spectrum analyzer with an omni-directional antenna was programmed to continuously scan the frequency band 5100-5250 MHz.[12] The results show significant RF power in 5170-5250 MHz, and insignificant RF power relative to the noise floor in 5096-5170 MHz. Spot checks of RF activity during the drive test using a Wi-Fi protocol analyzer reveal the presence of IEEE 802.11ac SSID's in channels 36 to 48, which fall within the frequency band 5170-5250 MHz.[13]

While these measurements are preliminary and by no means exhaustive, they provide strong evidence that the noise rise measured by Globalstar's satellites is caused by Wi-Fi access point emissions.

[11] *Globalstar Noise Floor Measurement Report* at pages 15-21.
[12] The details of the drive test are described in Appendix G.
[13] SSID is an acronym for Service Set Identifier which is the name associated with an IEEE 802.11 access point.

4. Analysis of Noise Rise in the Feeder Uplink Due to Wi-Fi Access Point Deployment

Overview

Recent U.S. Federal Communications Commission filings by counsel to NCTA[14] indicate that, as of June 2017, the cable industry had likely deployed in the U.S. approximately 10 million total indoor and outdoor unlicensed Wi-Fi access points in the U-NII-1 band at 5170-5250 MHz. Because of the large number of Wi-Fi interference sources operating in Globalstar's feeder uplink, the analysis of Wi-Fi interference and its effects will be described first. In Section 8, other potential sources of interference and noise rise to Globalstar will be discussed.

In evaluating the impact of outdoor U-NII-1 access point transmissions on Globalstar's MSS operations, the first step is to determine the degradation to the feeder uplink caused by the deployment of these unlicensed Wi-Fi access points. Degradation to the feeder uplink is measured as the increase in the noise floor ("noise rise") in the earth station gateway-to-satellite communication path caused by outdoor U-NII-1 access points deployed within view of the satellite receive antenna. Key access point parameters in the analysis of uplink noise rise are radiated power, the antenna gain characteristics, duty cycle, bandwidth, and geographic location. The noise rise as a function of the number of unlicensed access points deployed within view of the satellite antenna can then be assessed. The rise in noise floor is compared to the ITU-R recommendations for allowable interference levels to low earth-orbit satellite links. Section 5 compares the noise rise calculations from this section with measured results from Globalstar satellites.

The analysis of uplink noise rise begins with the interference noise model described in section 4.1. The model calculates the average interference power flux density at the satellite for comparison with a system noise power flux density. As discussed in Section 4.1.3, the interference power that results is proportional to the number of access points (APs) and their utilization level or transmission duty cycle.[15] Section 4.1.3 then compares the calculated results with measurements made by a satellite. Since the interference is present in the uplink spectrum shared by U-NII-1[16] and used by downlink spots 0-7, Section 4.1.3 re-calculates the main results of 4.1.2 for the U-NII-1 band and for the AP antenna that generates the least interference,[17] to represent a lower bound on the expected access point interference.

4.1 Interference Model

Interference at the satellite on the feeder uplink is analyzed in terms of the power flux density (Φ) incident on the satellite receiver antenna. The mathematical details are provided in Appendix E. The results show that the interference power flux density ($\Phi_{\text{interference}}$) will exceed ITU-R

[14] NCTA is the Internet and Television Association (www.ncta.com). It was previously named the National Cable and Television Association.
[15] AP will be frequently used in this report as an abbreviation for a Wi-Fi Access Point.
[16] IEEE 802.11 access point interference is present in 5170-5250 MHz of the U-NII-1 band.
[17] The omni-directional "stick" antenna.

recommended limits for as few as 7500 outdoor U-NII-1 access points, with access point emission characteristics conforming to the FCC's requirements for outdoor operation adopted in 2014.

ITU-R Recommended Limits

ITU-R Recommendation S.1426-0 (2000) specifies an upper limit on power flux density for interference for ground-based wireless LANs with satellites in the 5150-5250 MHz frequency band. The recommended limit for satellites at 1414 km altitude is -124 dBW/MHz-m^2. For other altitudes, the Recommendation is generalized to $-124 - 20 \log_{10}(H_{sat}/1414)$ dBW/MHz-m^2.

ITU-R Recommendation S.1432-1 (2006) defines upper limits on the allowable sensitivity degradation to satellites for frequencies below 30 GHz. The Recommendation distinguishes between satellite systems with co-primary status, both with and without frequency re-use, with slightly more stringent limits for the former. The recommended interference limit is set according to the system noise. The limiting value (see S.1432 Figure 1) is an I/N ratio of -12.2 dB. This yields a noise rise of 6% of system noise (noise rise = 0.25 dB). The system noise power flux density is calculated in Appendix E, equation E-3e, and this is summarized in equation 1.

$$\Phi_{noise} = -111.8 \text{ dBW/MHz-m}^2 \qquad \text{Eq. 1}$$

If we decrease Φ_{noise} by 12.2 dB according to the recommended I/N limit, then the limit on interference power flux density is -124.1 dBW/MHz-m^2. This is consistent with the recommended limit in Recommendation S.1426.

Recommendation S.1432 also sets a more stringent limit on interference from other systems with non-primary status, such as Wi-Fi access points. This recommended limit is 1% noise rise, equivalent to 0.04 dB, or an I/N ratio of -20 dB.

4.1.1 Unlicensed Wi-Fi Access Point Characteristics

The Federal Communications Commission issued revised regulations in 2014 in Section §15.407 (a) (1) (i) that permit outdoor operation for unlicensed wireless devices in the 5150-5250 MHz U-NII-1 band. The changes to power limits for outdoor access point (AP) operation include:

a) an increase in the power limits of operation to a maximum conducted power of 1 Watt with up to 6 dBi antenna gain (*i.e.* 4 Watts EIRP); and

b) a maximum EIRP of 125 mWatt at any elevation angle above 30° from the horizon. If directional antenna gain exceeds 6 dBi then the conducted power must be reduced dB-for-dB of excess gain.

The FCC's 2014 regulations also provided for fixed point-to-point operation, also with up to 1 Watt of conducted power, but with up to 23 dBi antenna gain (*i.e.*, 200 Watts EIRP). This provision is limited to point-to-point operation and specifically excludes point-to-multipoint and omnidirectional operation.

Mobile and portable outdoor clients in the U-NII-1 band are restricted to 250 mWatt maximum conducted power in the regulations.

An additional regulation (§15.407 (j)) requires operators deploying more than 1000 outdoor access points to "submit a letter to the Commission acknowledging that, should harmful interference to licensed services in this band occur, they will be required to take corrective action."

The Wi-Fi access point characteristics utilized in the analysis described here are based on the FCC regulations as follows:

> The conducted transmit power is 1 Watt.[18] When distributed over 80 MHz of spectrum in the U-NII-1 band, the conducted average power spectrum density is 0.0125 W/MHz.
>
> The AP antenna has a gain characteristic ($G_{AP}(\Omega)$) that restricts emission towards the zenith and focuses emissions to the horizon. Together with the conducted power of 1 Watt, these access point characteristics meet the 2014 emission requirements. In general terms, the types of antennas utilized in the analysis are representative of types actually deployed, and can be described as omnidirectional (stick) antennas, directional panel antennas, and high gain dish antennas used for point-to-point links. The gain patterns for the antenna types used in the analysis are described in Appendix B.

4.1.2 Interference Model

Terrestrial Radio Local Area Network (Wi-Fi) systems include APs distributed on the ground. A detailed calculation of the average interference power flux density from APs in the U-NII-1 band is described in Appendix E. The calculation averages the power flux density across the ground area viewed by the satellite, including the effects of antenna gain functions and shadows from building or terrain elevations. The geometry of the line of sight path from the ground to the satellite is shown in Appendix D. That appendix shows the calculation of the elevation angle, ε, from a geocentric angle, θ, for all ground locations within view of the satellite. For a satellite in orbit at 1414 km, the diameter of the viewing area on the ground under the satellite is 7800 km. The elevation angle above the local ground horizon can decrease to 0° at the edge of the satellite view of the ground, *i.e.*, anywhere on a circle of diameter 7800 km centered under the satellite.

The power flux density (Φ) from an AP at any point on the ground within view of the satellite is calculated by equation E-1a in Appendix E, multiplied by a *Shadow* function. The Φ function is shown here as equation 2.

---

[18] One Watt conducted power with a 6 dBi gain antenna yields 4 W EIRP. Use of power levels at the FCC specified limit in the interference calculation is justified by industry statements that outdoor RLANs are typically deployed at the maximum power level. For example, see "AT&T says 6 GHz band key for FirstNet, 5G" accessed at https://www.fiercewireless.com/wireless/at-t-says-6-ghz-band-key-for-firstnet-5g "("AT&T shared that its use of radio local area networks (RLANs) for LAA in the 5 GHz band shows that virtually all are operating at the highest allowable power, and most are operating at heights of 30 feet" [outdoors]).

$$\Phi(\theta) = \frac{P\ G_{AP}(\varepsilon)\ Shadow(\varepsilon)}{4\ \pi\ D(\theta)^2} \qquad \text{Eq.2}$$

The AP conducted transmitter power, P, is set to the limit of 1.0 W total, or 0.05 W/MHz in a 20 MHz channel bandwidth, or 0.0125 W/MHz for APs randomly distributed within an 80 MHz bandwidth at 5170-5250 MHz in the U-NII-1 band.[19] This calculation sets P=0.0125 W/MHz in equation 2, presuming a random AP spectrum distribution.

Each AP uses a transmit antenna with some antenna gain function $G_{AP}(\varepsilon)$ relative to an isotropic source, given in dBi as a function of elevation angle (ε). The antenna gain function G_{AP} depends on the antenna in use, so this calculation is repeated for some mixture of antenna gain functions, and then the power fluxes are averaged. Some example antenna gain functions are shown in Appendix B. The power flux density results for access points with different antennas are tabulated in Table 1.

The *Shadow*(ε) function in equation 2 accounts for building shadows at low elevation angles. This function is discussed and calculated in Appendix D. For some AP applications, such as point-to-point links, the building shadow function will not be a factor since point-to-point links are designed to propagate over paths free of any obstacles.

The distance variable D in equation 2 is the path length from the satellite to the ground location point. The variation of D with the geocentric angle θ is explained in Appendix D, equation D-6. The average power flux density for an AP at any point in the viewing area is found by integrating and averaging the $\Phi(\theta)$ function over the viewing area, as described in some detail in equation E-5b of Appendix E.

The calculated average power flux densities for each of the three antenna types in Appendix B are tabulated in Table 2 below. These calculations include the building and terrain factors explained in Appendix D. The table shows the average power flux density for a single AP randomly distributed within view of the satellite.

Table 2. Average Power Flux Densities for Different Access Point Antennas

Antenna	Φ_{avg} (per AP)	Relative Weight
Omni stick	-165 dBW/MHz-m^2	30%
Directional wall panel	-162 dBW/MHz-m^2	60%
Directional gain dish	-158 dBW/MHz-m^2	10%
Weighted Average	-162 dBW/MHz-m^2	

The Φ_{avg} results for all the antennas are within a range of 7 dB. Subsequent calculations of interference power assume a population of access points with a mix of antenna types. The mix produces a weighted average for the total interference flux density with weights of 30/60/10 for

[19] IEEE 802.11ac channel 42 is 5170-5250 MHz.

the stick/panel/dish antennas, respectively. The average yields a single Φ_{avg} to use for convenience in subsequent calculations of the impact to MSS capacity and user quality of service.

The entry in Table 2 for the directional dish antenna is the worst interference source in the table. The directional dish antenna is intended for point-to-point links, and point-to-point links are designed to be free of any terrestrial obstacles (no buildings or terrain). This is why the Φ_{avg} for the dish is somewhat higher than the other antennas. The higher flux comes from AP transmitters at the edge of the satellite viewing area with elevation angles under 10°. For the mix of antenna types assumed, essentially, the entire unattenuated transmit power is directed to satellites in orbit for a subset of about 1/10 of the point-to-point links.

4.1.3 Noise Rise Results

The average power flux densities from each type of AP antenna are combined into one weighted average interference power flux density on the bottom line of Table 2. This average power increases linearly with more APs. Since the viewing area is 46.3 million km^2 (see Appendix D, equation D-8), there is considerable room to distribute APs on the ground. The average flux density in 5170-5250 MHz of the U-NII-1 band as a function of the number of APs is plotted on a graph in Figure 7.

To show the impact of duty cycle and access point utilization, Figure 7 shows the power flux densities for APs transmitting 100% of the time, as well as 80%, 40%, 20% and 10%. The number of AP transmitters varies from 100 to 10 million on a logarithmic scale. Short horizontal lines show the flux limits mentioned in the ITU-R recommendations. The ITU-R Recommendation S.1426 limit of -124 dBW/MHz-m^2 is reached with 7,500 APs and a 80% duty cycle. At the satellite, this would yield a noise rise of 0.25 dB in the feeder uplink band at 5170-5250 MHz. The noise power flux density reaches the system noise limit of -112 dBW/MHz-m^2 with 110,000 APs and an 80% duty cycle. This would create a noise rise of 3 dB in the U-NII-1 band, representing a serious degradation of a LEO satellite system.

Another way to view this result is to plot the noise rise in the total 154 MHz bandwidth of the uplink as a function of the number of APs. Figure 8 shows the total noise rise in 154 MHz of spectrum as increasing significantly beyond 3 dB as the number of APs increases beyond 200,000. For 4 million outdoor access points at 10% duty cycle, the noise rise is 5 dB, while for 4 million access points at 80% duty cycle, the noise rise reaches nearly 13 dB.

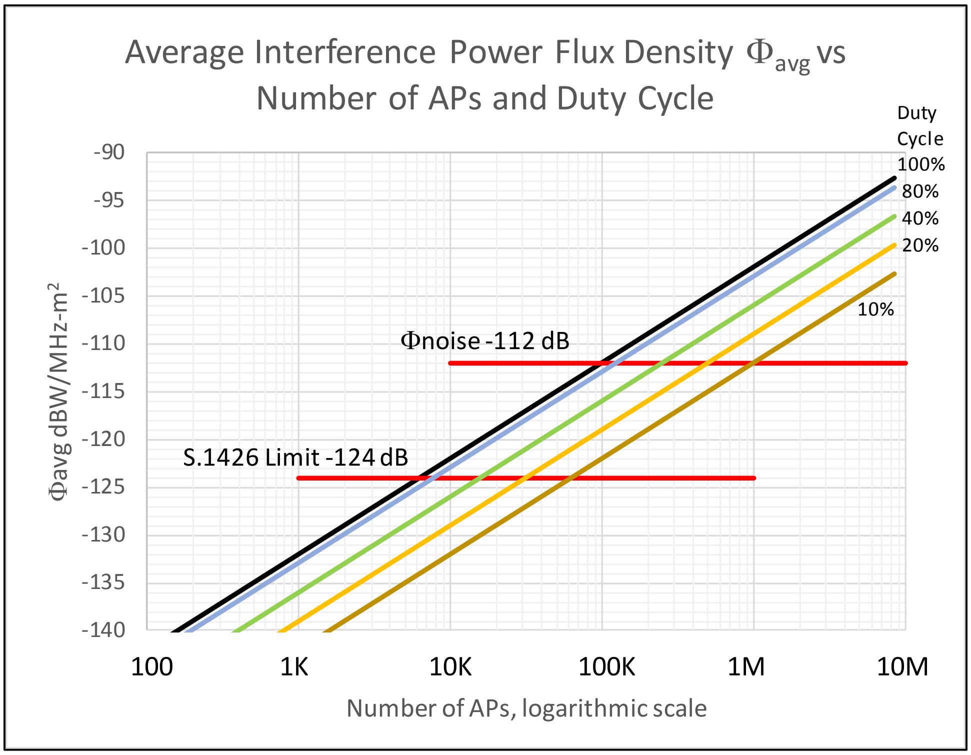

Figure 7: Average Interference Power Flux Density

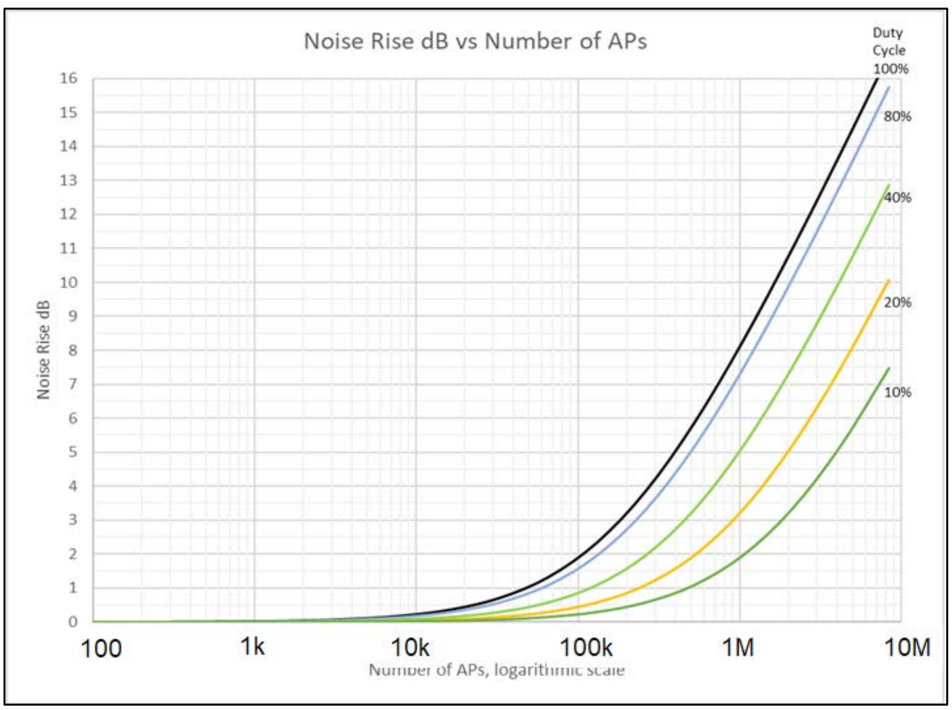

Figure 8: Noise Rise in 150 MHz Uplink for Number of APs (mix of antenna types)

Access Point Density

Access point deployment density is a critical parameter in the calculation of interference, since it determines the total likely number of outdoor U-NII-1 access points within view of the satellite,[20] which in turn affects the likely noise rise at the satellite.

Analysis shows that more than 4 million Wi-Fi access points could eventually be operational outdoors in North America. This number is based on Google's early, free Wi-Fi deployment in Mountain View, California, from which access point density was calculated in 2013 to be 16 access points per square kilometer. In 2017 this density increased to 23 AP/km^2,[21] for an even larger number of future outdoor access points. Extrapolation of this AP density to all urban areas in the United States yields an estimate of 4 million outdoor access points. The calculation is detailed in Appendix A. This level of outdoor Wi-Fi density is substantial enough to enable subscribers to reach an access point within a few hundred meters of their location. Several U.S. cities have begun deployments with this access point density, including New York City, New York, and Minneapolis, Minnesota.

One important aspect of access point density is the number of subscribers to be served. A density of 16 APs/km^2 is sufficient for up to 160 subscribers/km^2; in this scenario, one AP could serve ten subscribers and one Wi-Fi channel. If the density of outdoor subscribers approaches saturation for the available bandwidth, then additional APs could be deployed to increase the density of APs and keep pace with subscriber demand for services. Such high subscriber densities are easily observed today at events such as sports stadiums, holiday parades, political rallies, musical concerts, and shopping centers.

The deployment of access points is assumed to be concentrated in urban and suburban areas, which is a small part (less than 1%) of the total surface area within a satellite's view. Since the satellite and the earth move significantly over a meaningful period of time, such as 10 minutes, the approach used here is to average the propagation distances and angles over the entire surface area for all of the APs within view of the satellite.

The immediate effect of an interference noise power flux incident on the satellite receiver antenna is to increase the receiver noise floor. This is conventionally measured as a 'noise rise' by taking the power ratio of the interference (I) + noise (N) with the noise power (absent any interference). This is expressed in equation 3. The interference power (I) is found by integrating the flux density ($\Phi_{\text{interference}}$) over the 80 MHz of the U-NII-1 band, while the noise power (N) is found by integrating the flux density of the system noise (Φ_{noise}) over the full 154 MHz of the ground-to-satellite uplink.

$$\text{Noise Rise (dB)} = 10\,log_{10}\left(\frac{I+N}{N}\right) = 10\,log_{10}\left(1+\frac{I}{N}\right) \qquad \text{Eq. 3}$$

[20] The text uses the term Wi-Fi access point or Wi-Fi hotspot interchangeably with Wi-Fi Access Point, or more simply AP. The Wi-Fi hotspot term is popular in US advertisements.
[21] *See* Appendix B, Figure 27.

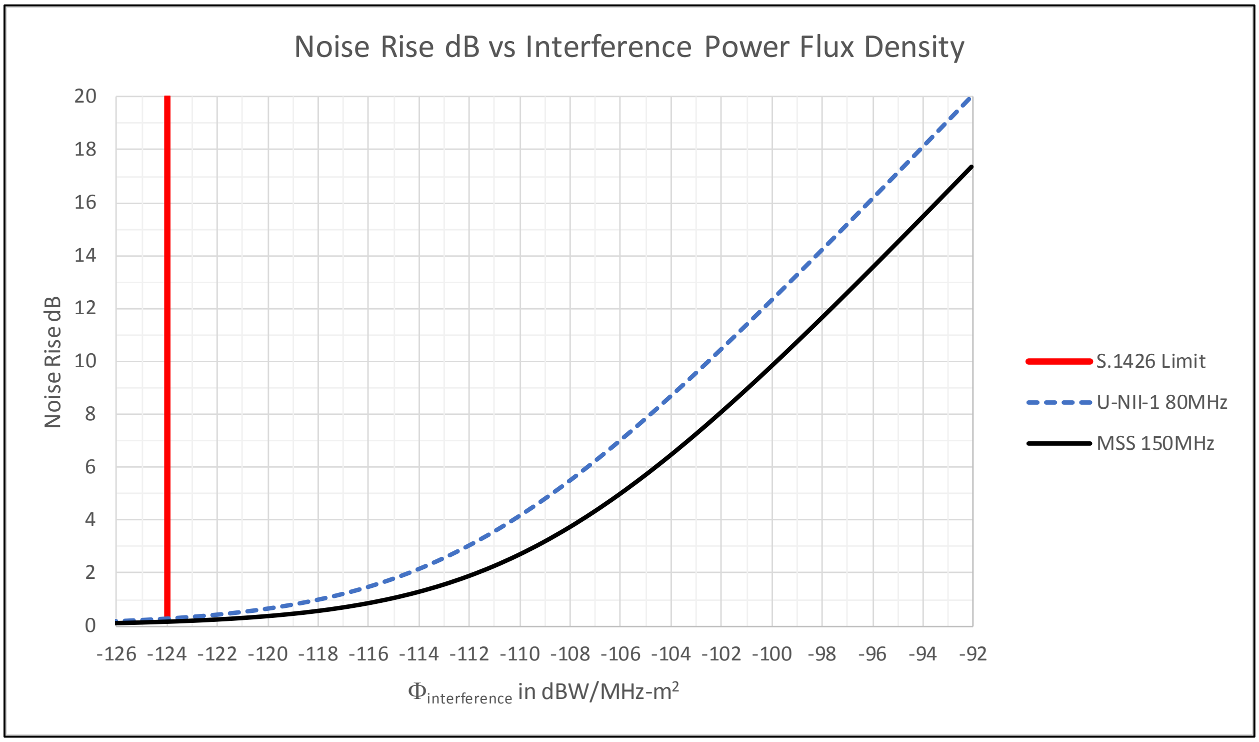

Figure 9: Noise Rise vs. Interference Power Flux Density

ITU-R Recommendation S.1432 sets a limit of 0.25 dB for the noise rise. This is obtained with an I/N ratio of -12.2 dB. The system noise flux density was previously computed in equation 1 to be -112.1 dBW/MHz-m^2. The noise rise is plotted in Figure 9 for the interference power flux density at the satellite. The dashed line shows the noise rise for the sub-channels in the U-NII-1 band, and the curve with the solid line shows the noise rise as measured over the entire 154 MHz bandwidth of the uplink. The graph shows that the noise rise over the entire 154 MHz bandwidth is as much as a few dB less than the noise rise within the 80 MHz U-NII-1 band, because the additional bandwidth has a dilution effect on the interference power measured at the satellite. The converse is also true: the noise rise within the 80 MHz bandwidth overlapping with U-NII-1 is higher than the noise rise measured over the entire 154 MHz bandwidth.

Another way to analyze the noise rise is to plot noise rise contours on a graph as functions of the number of APs and their average duty cycle for the transmitter. This is shown in Figure 10. The plot shows noise rise for APs using only the omnidirectional stick antennas described in Appendix B. This is the least interfering antenna choice. The noise rise contours begin with the ITU-R recommended limit of 0.25 dB. This restricts the number of APs to less than 30,000 in the satellite viewing area if the average duty cycle reaches 80%. In the 154 MHz bandwidth of its satellites (5096-5250 MHz), Globalstar has recently measured a noise rise over North America of 1 to 2 dB compared to the noise floor over other regions.[22] Figure 10 shows that a 1 dB noise rise is consistent with about 4 million outdoor U-NII-1 access points operating at an average 2.5% duty cycle, or one million outdoor U-NII-1 access points operating at a 10% duty cycle. The figure also

[22] *Globalstar Noise Floor Measurement Report*.

shows that a 2 dB noise rise is consistent with about 4 million outdoor U-NII-1 APs operating at 6% duty cycle, one million APs operating at a 23% duty cycle, or 600,000 APs operating at a 40% duty cycle. The graph clearly shows that other combinations of access points numbers and their average duty cycles can produce the same noise rise levels.

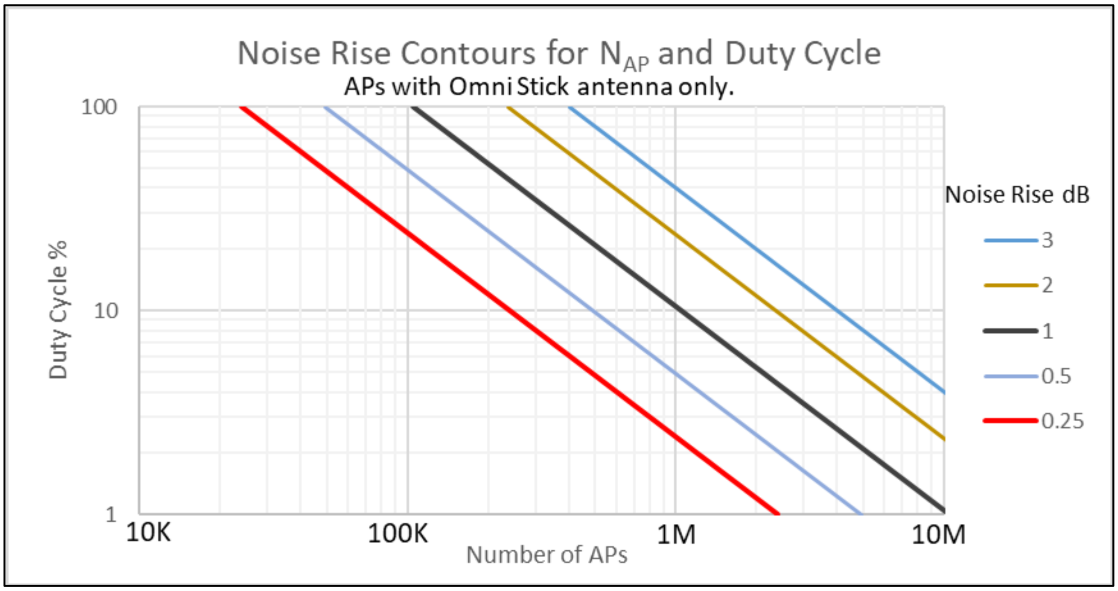

Figure 10: Noise Rise Contours for APs with Omni Stick Antennas

The end-to-end C/N ratio for the MSS satellite system is related to the individual C/N ratios for the uplink and downlink in equation 4. This is described in more detail in Section 6.2 (see equation 5 there), so here only the immediate effects of noise rise are discussed. In equation 4 the noise powers on the uplink and downlink are represented by N_{up} and N_{down}, respectively. The interference power on the uplink is given by I_{up}. The immediate effect of a significant noise rise on the uplink from any increase in I_{up}, is to limit the maximum possible $(C/N)_{total}$ delivered to subscribers on the down-link. This is experienced by the system subscribers as a 'choke' on the grade of service. This consequence is illustrated for some example C/N values in the graph in Figure 11.

$$\left(\frac{C}{N}\right)_{total} = \left(\left(\frac{C}{I_{up}+N_{up}}\right)^{-1} + \left(\frac{C}{N_{down}}\right)^{-1}\right)^{-1} \qquad \text{Eq. 4}$$

A degradation in $(C/N)_{total}$ also has an immediate effect on system capacity as a whole. The CDMA technology in the MSS system depends on power control to distribute the available budget of transmit power to the subscribers for the best grade of service. A degradation in the $(C/N)_{total}$ causes a system response that either degrades service for all subscribers, or reduces the load (*i.e.* reduce the number of subscribers) so that more power can be used to sustain a necessary grade of service. These tradeoffs are described more fully in Sections 6.3 and 6.4.

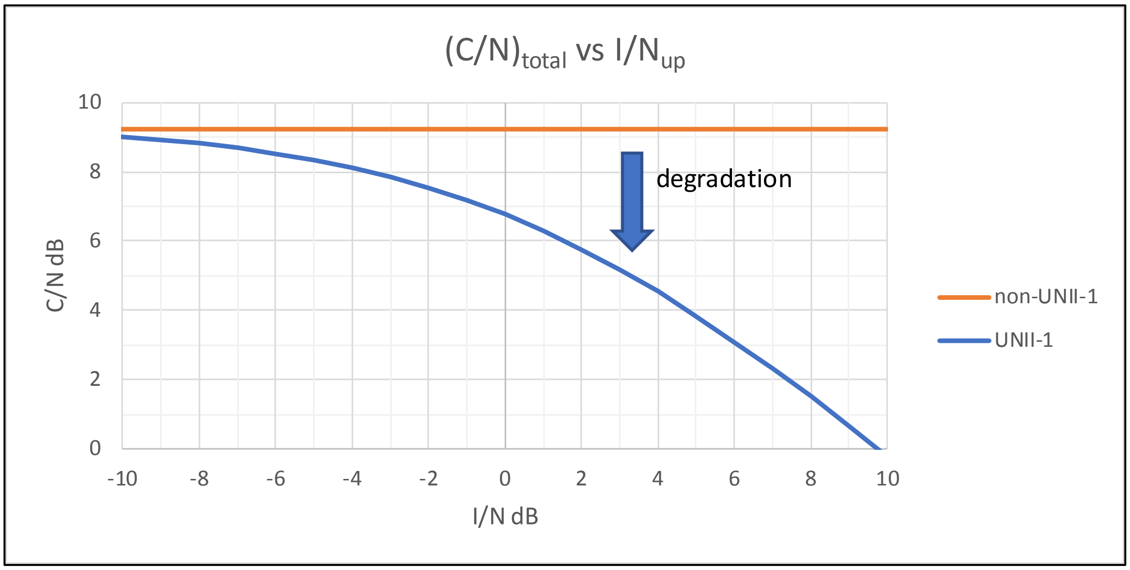

Figure 11: $(C/N)_{total}$ for Interference to Noise Ratio

5. Comparison of Predicted, Measured, and Future Noise Rise (Interference)

5.1 Number of Unlicensed Access Points Deployed in 2017

Recent U.S. Federal Communications Commission filings by counsel to NCTA indicate that, as of June 2017, the cable industry had likely deployed in the U.S. approximately 10 million total indoor and outdoor unlicensed Wi-Fi access points in the U-NII-1 band at 5170-5250 MHz.[23] As previously shown in the analysis in Section 4.1, the deployment and operational parameters of access points influence the degradation to the MSS feeder uplink as measured by noise rise. The previous analysis assumes that all of the operational U-NII-1 access points are deployed outdoors. The proportion of these access points that are in fact deployed outdoors impacts the noise rise that will be experienced by Globalstar's MSS satellites, as does the average access point duty cycle, transmitted power, and antenna gain pattern. These factors will be taken into account when comparing noise rise predicted by the analysis in Section 4.1, and the actual noise rise experienced by the Globalstar system.

[23] The FCC filing, "Comments of NCTA-The Internet & Television Association; in the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz., October 2, 2017," states that 19.7 million total access points were deployed by NCTA members. The October 12, 2016 ex parte filing re ET Docket 13-49, by Harris, Wiltshire, and Grannis, LLP, counsel for NCTA, the Internet Television Association, states that in October 2016, NCTA members have deployed a total of approximately 16 million public cable Wi-Fi hotspots, with 54% of the access points deployed by NCTA members in the U.S. U-NII-1 band. This corresponds to 10 million access points in the 5170-5250 MHz portion of the U-NII-1 band in June 2017.

5.2 Noise Rise in 5170-5250 MHz and Comparison of Predicted and Measured Noise Rise

As described above in Section 3, since the FCC authorized the deployment of outdoor U-NII-1 access points in 2014, Globalstar has measured the noise floor for its satellite feeder uplinks on a regular basis as its satellites pass over the United States. The Globalstar Noise Floor Measurement Report indicates that the noise floor measured while the satellite was over Lincoln Center, Kansas, on June 6, 2017 was 1 ± 0.5 dB higher than the noise floor measured in 2014, and also 1 ± 0.5 dB higher than when measured over areas outside the United States.[24] Recognizing that (1) Globalstar measures noise rise in its entire feeder uplink receive bandwidth at 5096-5250 MHz and (2) the unlicensed Wi-Fi access point emissions are in the 5170-5250 MHz band (IEEE 802.11ac standard channels), the noise rise experienced by the MSS CDMA channels in the 5170-5250 MHz band is 1.8 ± 0.8 dB. The CDMA channels that experience the direct effects of this noise rise are the central spots 0-6 in the downlink shown in Figure 4, plus spot 7. When the satellite is over Lincoln Center, Kansas, these spots cover an area equal to 95% of the land area of the continental United States.

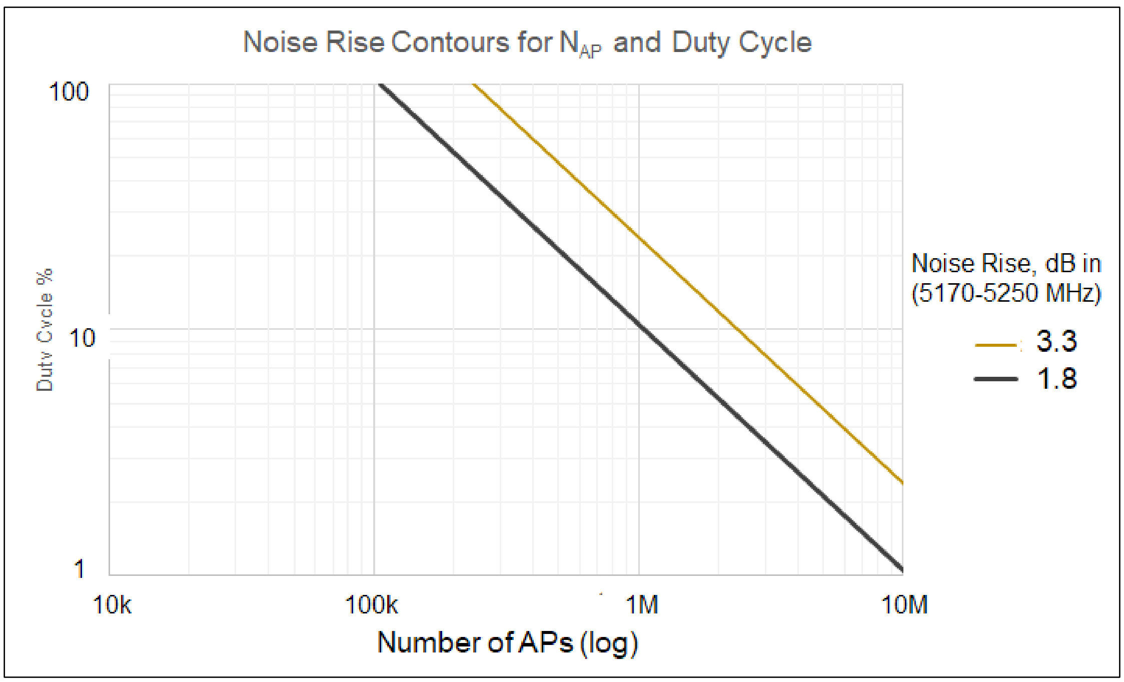

Figure 12: Noise Rise Contours for Measured Noise Rise

Based on NCTA's disclosure in FCC filings regarding the actual number of access points deployed in the 5170-5250 MHz band, a comparison can be made between the noise rise predicted by the analysis in Section 4.1 and the actual noise rise observed by the MSS satellites in 5170-5250 MHz. This comparison is shown in Figure 12 as the line corresponding to 1.8 dB noise rise. If 10% (or approximately one million) of the 10 million access points claimed to be deployed by the NCTA are

[24] *Globalstar Noise Floor Measurement Report* at pages 21-24.

in use outdoors, then the noise rise is consistent with a business hour access point duty cycle of 10%. As the graph shows, the same observed noise rise would be produced by other combinations of likely duty cycles and numbers of outdoor U-NII-1 access points. For example, 250,000 AP's operating at an average duty cycle of 40% or 500,000 APs operating at an average duty cycle of 20% also produce this noise rise. Overall, the analysis of noise rise presented in Section 4 is consistent with measured results and disclosed U-NII-1 access point AP deployments. The 3.3 ± 0.7 dB noise rise plot corresponds to 2 ± 0.5 dB noise rise in 5096-5250 MHz currently being observed on 6 of the 8 satellites being monitored by Globalstar. The 3.3 ± 0.7 dB plot indicates that either the number of outdoor access points, or their average duty cycles, or both, have increased from June 2017 to the present.

5.3 Predicted Noise Rise in Affected CDMA Channels

Section 5.2 showed a noise rise in the 5096-5250 MHz band, with a bandwidth of 154 MHz. This is consistent with noise rise measurements by the MSS satellites of 1 ± 0.5 dB. The Wi-Fi interference that creates this noise rise is limited within the U-NII-1 band to 5170-5250 MHz, or a bandwidth of 80 MHz. A noise rise measurement restricted to the U-NII-1 band would show more than the measured result from the MSS satellite. This effect is shown by the noise rise graph in Figure 9. Figure 9 shows a noise rise of 1 dB in 154 MHz (shown by the solid line curve), corresponding to a noise rise of 1.8 dB in 80 MHz (shown by the dotted line curve).

The direct effect of the noise rise from the U-NII-1 band is to add interference to downlink spots 0 through 7 shown in Figure 4. When the satellite is over the central U.S., these spots cover an area of 95% of the land area of the continental US. The area is also in the center of the overall service area of the satellite. Section 6 will analyze the effects of the noise rise on CDMA system operation, and those effects directly impact service in spots 0 through 7. This section therefore shows noise rise results for the feeder uplink in the U-NII-1 band, using the same calculations previously described in Section 4.1 for the 5096-5250 MHz band.

Previous Section 4.1 analyzed the noise rise effects from different AP antennas, including the omni-directional stick antenna and a directional panel antenna. The noise rise results in this section will consider only the effects from omni-directional stick antennas. A brief look at Figure 9 shows that the noise rise in the 5150-5250 MHz U-NII-1 band will be higher than the noise rise measured in the 5096-5250 MHz band. The power flux density results in Table 2 further show that the noise rise produced if all access points use the omni-stick antenna is about 3 dB lower than the weighted average for all the antennas. The two effects oppose each other with a net effect of a slightly lower noise rise for results in this section for access points with an omni-stick antenna as compared to other results in Section 4.1.

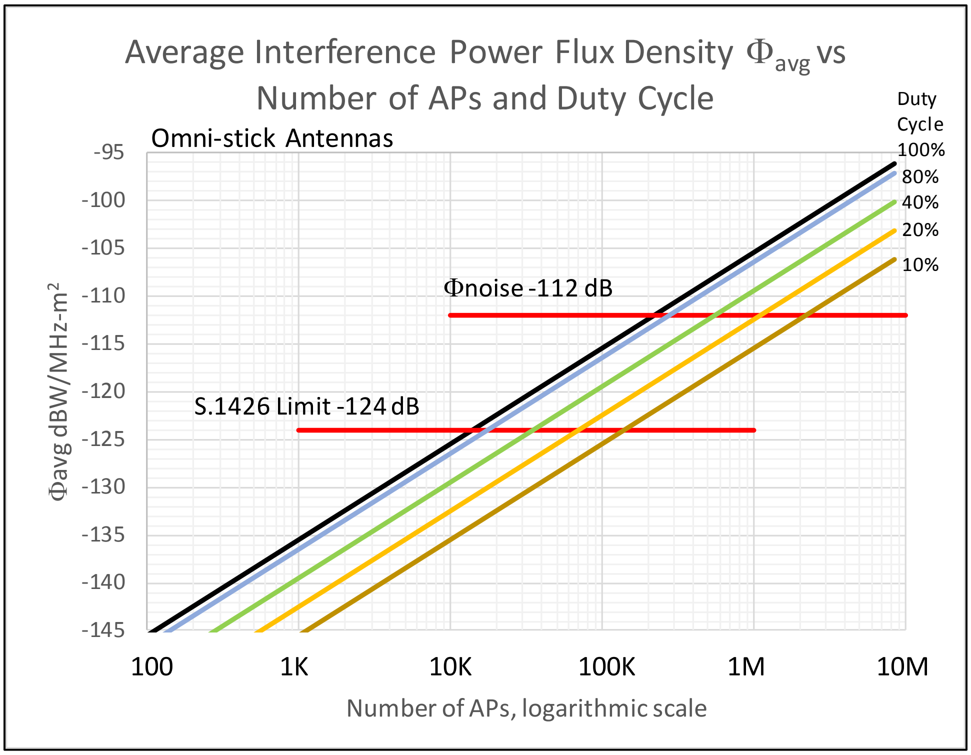

Figure 13: Average Interference Power Flux Density for Omni-Stick Antenna

Figure 13 is a re-calculated version of Figure 7, showing the power flux density as just a function of the number of APs with omni-stick antennas. The number of APs varies from 100 to 10 million and the duty cycle varies from 100% down to 10%.[25] The ITU-R Recommendation S.1426 limit of -124 dBW/MHz-m^2 is reached at 16,000 APs with 80% duty cycle, and this will create a noise rise at the satellite of 0.25 dB. The system noise level of -112 dB is reached for 250,000 APs with 80% duty cycle, which would create a noise rise of 3 dB at the satellite, or an I/N ratio of 0 dB.

5.3.1 Comparison of Predicted and Actual Noise Rise in 5170-5250 MHz

As described in Section 5.1, recent filings by the NCTA to the FCC indicate that, as of June 2017, the cable industry had deployed in the U.S. approximately 10 million unlicensed Wi-Fi access points in the U-NII-1 band at 5170-5250 MHz.

Figure 14 is a re-calculated version of Figure 8, showing the noise rise in a 5170-5250 MHz bandwidth if all the APs used omni-stick antennas, which is a reasonable assumption for outdoor access points deployed by the cable industry.[26] The scale shows the number of APs varying from 1 thousand to 100 million, while the duty cycle varies from 10% to 100%, thereby showing the

[25] It is understood that 100% transmitter duty cycle is not possible for a Wi-Fi access point, although it may be possible for a point-to-point communication link operating in the unlicensed band. 100% duty cycle is shown to illustrate the noise rise limit as transmitter duty cycle increases.
[26] This assumption results in less impact to Globalstar than a mix of access points with omni, panel, and dish antennas, and therefore sets a *lower* bound on the expected impact to Globalstar.

sensitivity to the utilization level. The figure shows the noise rise at 5170-5250 MHz increasing beyond 3 dB for more than 250 thousand APs with 80% duty cycle, or two million APs with 10% duty cycle. A 1.8 dB noise rise in the U-NII-1 band is reached for one million APs at 10% duty cycle.

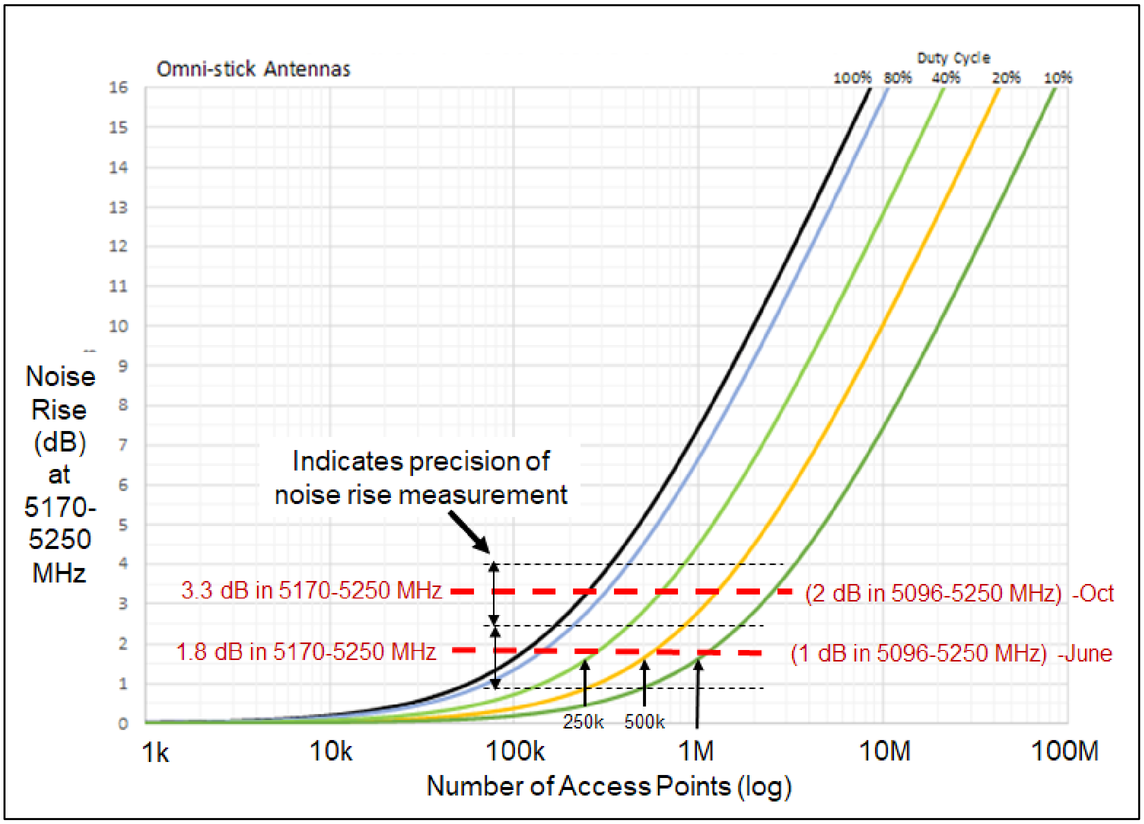

Figure 14: Noise Rise in 5170-5250 MHz versus Number of Outdoor APs and Duty Cycle

The Globalstar noise rise measurements at the satellite in May 2017 are summarized in Section 4, indicating 1 ± 0.5 dB noise rise over a receive bandwidth of 154 MHz. There are no access points deployed at 5096-5170 MHz, since there are no IEEE 802.11 channels authorized there.[27] Therefore the 1 ± 0.5 dB rise measured by Globalstar is attributed to a 1.8 ± 0.8 dB rise at 5170-5250 MHz, the frequency band where the Wi-Fi access point interference is generated. If one million (or 10% of the total 10 million U-NII-1 access points that have likely been deployed by cable operators, according to NCTA) are deployed outdoors, then the calculation of noise rise reflected in Figure 14 of 1.8 ± 0.8 dB is consistent with an actual noise rise of 1.8 ± 0.8 dB at 5170-5250 MHz over North America in May 2017.[28] Since the exact number of outdoor U-NII-1 access points has not been disclosed, an important observation is that other likely combinations of the fraction of outdoor

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[27] The LTE-U Forum has designated channels for LTE-Unlicensed in 5150-5250 MHz. Although Verizon is on record as testing LTE-U in 5150-5250 MHz, there is currently no evidence of large scale deployment. *See* https://www.fiercewireless.com/tech/verizon-to-test-pre-commercial-lte-u-small-cells-unlicensed-5-ghz-band.

[28] *Globalstar Noise Floor Measurement Report*.

access points and their duty cycles could also produce the 1.8 ± 0.8 dB rise. For example, this noise level increase would also result from 5% outdoor or 500,000 U-NII-1 access points operating at a busy period duty cycle of 20%, or 2.5% outdoor or 250,000 access points operating at a duty cycle of 40%.[29] Significantly, the deployment of one million outdoor or even 500,000 U-NII-1 access points in June 2017 far exceeds NCTA's 2014 projection and analysis that there would be a maximum of 250,000 outdoor access points in the U-NII-1 band.[30]

Over time, access point duty cycles will increase due to an increase in the number of users and increased data usage per user. The increase in data consumed per user is well documented in reports such as Cisco's Visual Networking Index.[31] The number of access points will also increase as operators seek to provide service over larger geographic areas. Evidence and forecasts for the increase in the number of access points over time are discussed below in Section 5.3.3. An increased access point duty cycle and a larger number of outdoor U-NII-1 access points will have a clear impact on the noise rise in Globalstar's feeder uplink spectrum, as shown in Figure 14. If an average busy-period duty cycle of one million outdoor U-NII-1 access points increases from 10% to 20% as a result of increasing user data consumption and greater number of users, then the noise rise increases to 3 dB. Furthermore, if the number of outdoor U-NII-1 access points doubles from one million to two million, the noise rise would also increase to 3 dB. Significantly, beginning in October 2017 Globalstar began measuring a noise rise of 2 ± 0.5 dB at multiple satellites over the U.S. and is currently measuring a 2 dB rise at 6 of its 8 satellites being monitored, in a bandwidth of 154 MHz. This is attributed to a 3.3 ± 0.7 dB noise rise at 5170-5250 MHz, the frequency band of operation of Wi-Fi access points in the U-NII-1 band.[32] This is consistent with growth in the number of access points reported by the NCTA,[33] coupled with likely increased access point duty cycles during the time period June 2017 to the present.

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[29] The 2014 NCTA analysis of U-NII-1 interference utilized a 40% AP duty cycle. *See 5 GHz UNII-1: Wi-Fi and Globalstar Sharing Analysis*, Rob Alderfer, CableLabs, Dirk Grunwald and Kenneth Baker, University of Colorado ("NCTA Report"), attached to Letter from Rick Chessen, NCTA, to Julius Knapp, FCC, ET Docket No. 13-49 (Jan. 22, 2014).

[30] Grunwald, Dirk and Alderfer, Rob and Baker, Kenneth R., "Sophisticated Wireless Interference Analysis: A Case Study for Spectrum Sharing Policy" (March 19, 2014). 2014 TPRC Conference Paper. Available at SSRN: https://ssrn.com/abstract=2411597 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2411597##, and *Attachment to January 22, 2014 filing by the NCTA*, Re: Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, ET Docket No. 13-49, "5 GHz UNII-1: Wi-Fi and Globalstar Sharing Analysis."

[31] Cisco forecasts that by 2021, mobile-connected tablets and PCs will generate double the amount of traffic as they did in 2016. *See Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021,* Document ID:1454457600805266, March 28, 2017, accessed at https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html#AnalyzingtheExpandingRole.

[32] *Globalstar Noise Floor Measurement Report*.

[33] FCC filing, "Comments of NCTA-The Internet & Television Association; in the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz., October 2, 2017," states that 19.7 million total access points were deployed by NCTA members. The October 12, 2016 ex parte filing re ET Docket 13-49, by Harris, Wiltshire, and Grannis, LLP, counsel for NCTA, the Internet Television Association, states that in October

5.3.2 Relationship of Noise Rise to Number of Access Points and Their Duty Cycle

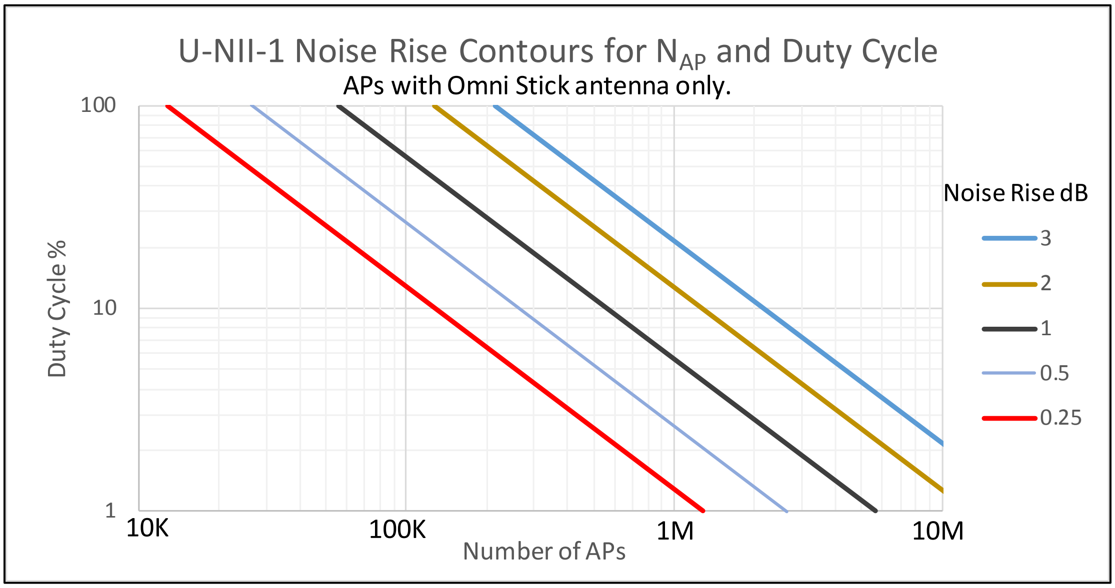

Figure 15: Noise Rise Contours in 5170-5250 MHz for Omni-Stick Antennas

Figure 15 is a re-calculated version of Figure 10, showing contours of duty cycle with number of APs to obtain noise rises at 5170-5250 MHz from 3 dB down to 0.25 dB. The 0.25 dB contour corresponds to the recommended interference threshold specified in ITU-R Recommendation S.1426. Adherence to the ITU threshold would restrict the number of outdoor U-NII-1 APs to less than 15 thousand if those access points are permitted to reach 80% duty cycle, or 130 thousand if the APs are restricted to less than 10% duty cycle.

5.3.3 Forecast of Future Interference and Noise Rise Increases

Recently reported industry information provides an indication of how the population of access points in the U-NII-1 band will likely increase in the future. The recent Cisco Virtual Networking Index (VNI) report indicates that there will be a six-fold increase in public Wi-Fi access points from 2016-2021. This is equivalent to a compound annual growth rate of 43%.[34] Applying this overall growth rate to the U-NII-1 band for the period 2017-2022, Figure 16 shows that if there were one million outdoor U-NII-1 access points in 2017 (consistent with Globalstar's satellite noise rise measurements), then there will be as many as 6 million outdoor U-NII-1 access points in 2022.

2016, NCTA members have deployed a total of approximately 16 million public cable Wi-Fi hotspots, with 54% of the access points deployed by NCTA members in the U.S. U-NII-1 band. This corresponds to 10 million access points in 5170-5250 MHz in June 2017.

[34] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021, Document ID:1454457600805266, March 28, 2017, accessed at https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html#AnalyzingtheExpandingRole.

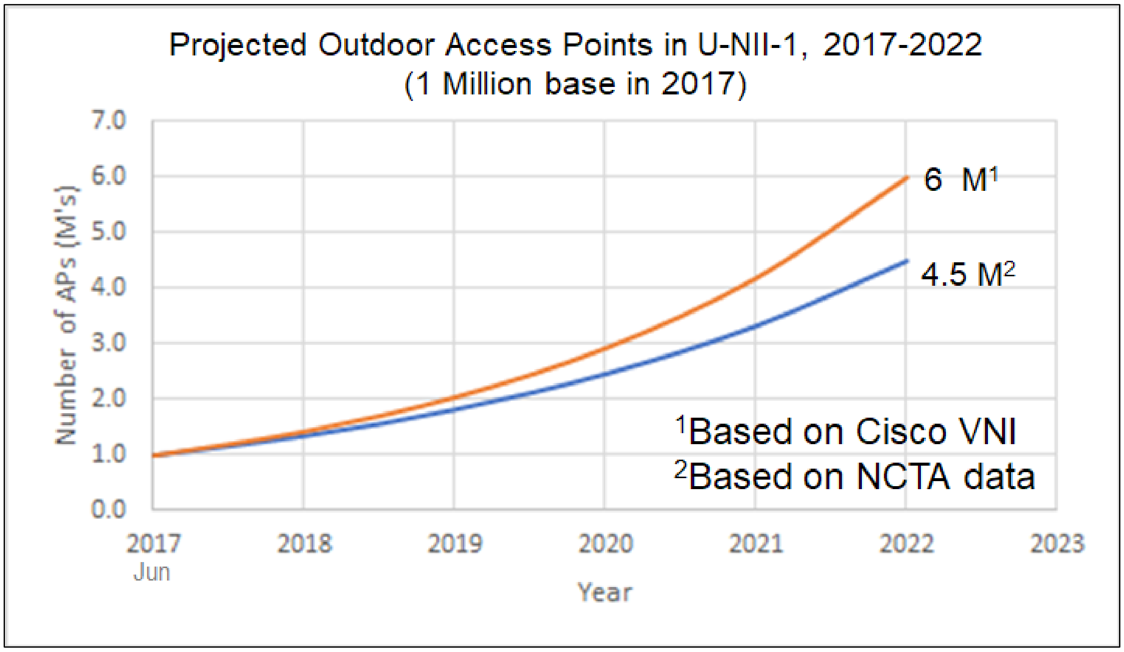

Figure 16: Projected U-NII-1 Access Point Growth, 2017-2022 for Base of One Million

In October 2016, NCTA reported that the cable industry alone had deployed a total of 16 million access points in all bands, with 54% in the U-NII-1 band. In June 2017, NCTA reported that 19.7 million access points were deployed in all bands, equivalent to a compound annual growth rate of 35%, slightly lower than that of the VNI. Applying this growth rate to the U-NII-1 band for the period 2017-2022, Figure 16 shows that if there were one million outdoor U-NII-1 access points in 2017 (consistent with Globalstar's noise rise measurements), then there would be as many as 4.5 million outdoor U-NII-1 access points in 2022. This is not an unreasonably large number of total access points for the U.S. in the U-NII-1 band. The calculation of the number of outdoor access points in Section 4.1.3 based on actual deployment densities resulted in numbers in excess of 4 million.[35]

The projected access point growth in Figure 16 and the above-described relationship between the number of access points and noise rise (see Figure 14) together enable a projection of the noise rise at 5170-5250 MHz for the period 2017-2022. Figure 17 shows that, based on industry projections of the increase in the number of access points, the noise rise experienced by Globalstar in the 5170-5250 MHz band would increase from 1.8 ± 0.8 dB in June 2017 to either 4.7 dB or 5.8 dB for a 10% duty cycle, based on the NCTA or Cisco data, respectively.[36] For a 20% duty cycle, the noise rise would increase to 6.9 or 8.2 dB, respectively. Recognizing that currently Globalstar is measuring a 2 dB noise rise in 6 of the 8 satellites that it is monitoring, (corresponding to 3.3 ± 0.7 dB in 5170-5250 MHz), it appears that both the increase in the access point utilization as a result of greater

[35] Google's initial access point density in Mountain View of 16 AP/km-sq results in 4.5 million APs for nationwide urban deployment. The current (2017) deployment density of 23 AP/sq-km results in 5.75 million APs for nationwide urban deployment.
[36] The brackets around the noise floor measurements in Figure 17 represent the accuracy of the measurements.

user data consumption, as well as the growth in the number of access points, is contributing to the increase in the noise floor experienced by Globalstar's satellites.[37]

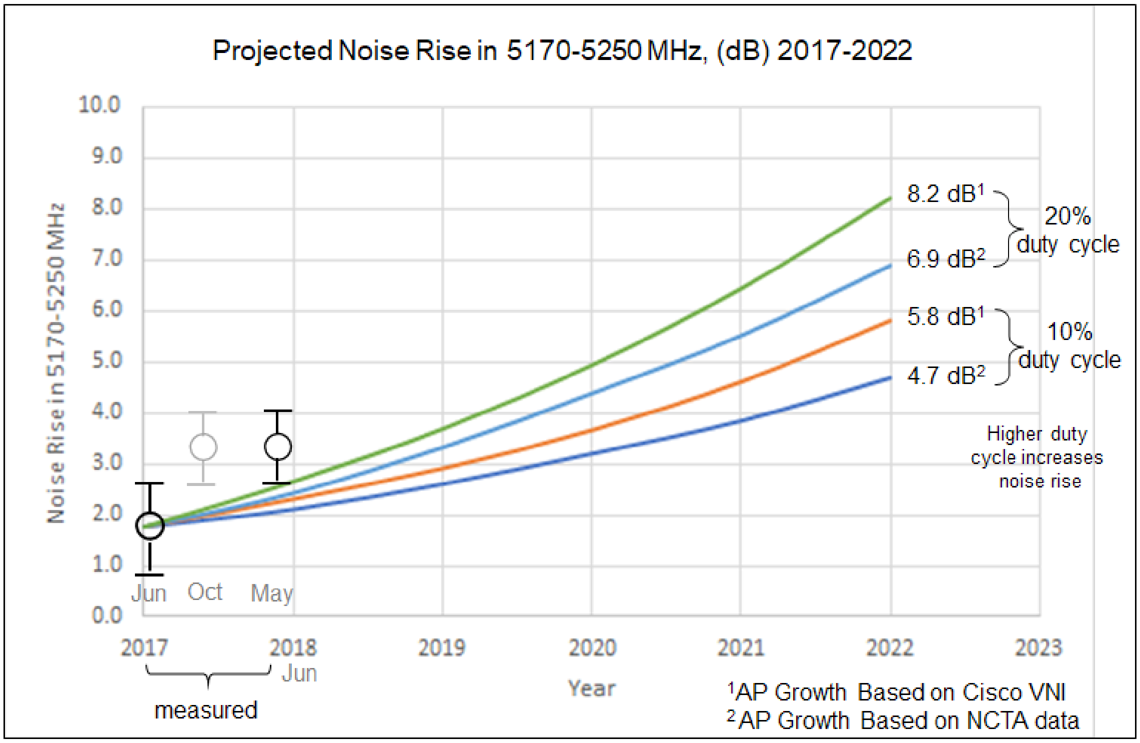

Figure 17: Projected Noise Rise Increase, 2017-2022, Due to Access Point Growth

[37] Access point duty cycles of 80% can be expected in the future as user demand increases. Operation at 80% duty cycle is supported by studies that show that the maximum downlink capacity is achieved at this level (*see* Nickolas J. LaSorte, Dan Bloom, et al., "Comparison of Duty Cycle Measurement Techniques of 802.11b/g in the Frequency and Time Domain," *Instrumentation and Measurement Technology Conference (I2MTC), 2013 IEEE International*, 6-9 May 2013, Minneapolis, MN.)

6. Operational Impact to Globalstar by Noise Rise in the Feeder Uplink

Successful satellite system service is dependent on a balance between the following performance requirements and operational constraints: the amount of RF power that must be transmitted to the user devices, the finite amount of satellite RF transmit power available, the feeder uplink and overall RF signal-to-noise-plus-interference, the geographic service availability, and the user capacity (maximum number of active calls that can be simultaneously supported). The introduction of outdoor unlicensed access points at 5170 to 5250 MHz causes an increase in the level of undesired interference in the MSS earth-station-to-satellite feeder uplink, affecting the user capacity of the satellite, the satellite RF transmit power available (which also affects the user capacity), and the geographic service availability. The analyses in this section evaluate the effect of outdoor U-NII-1 Wi-Fi access point interference on all these satellite performance metrics, as well as on the coverage reliability (user quality of service).

Due to the "bent pipe" transponder architecture of Globalstar's satellite network, the end effect of the interference in the Globalstar gateway-to-satellite uplink is manifested as a decrease in the signal to noise ratio at the mobile user device receiver. The straightforward relationship between the Globalstar uplink and downlink allows the effect on the satellite downlink to be calculated. Three types of degradations are analyzed: 1) the decrease in satellite-to-user device downlink CDMA capacity due to the uplink noise rise; 2) the decrease in RF power available at the satellite for communication to the user devices, which also results in a satellite user capacity reduction; and 3) the degradation in service availability (geographic coverage) to subscribers, which also increases the number of dropped calls and failed call attempts.

The previous Section 5 described how interference on the feeder uplink causes a significant noise rise at the satellite. Section 6.1 below describes how to assess the effects of interference on the satellite system and its users. The relationship between noise rise on the feeder uplink and the satellite downlink C/N ratio is described in Section 6.2. Sections 6.3 and 6.4 describe the effects of noise rise on CDMA user capacity and satellite RF power capacity, respectively. These results are then extended in Section 7 to show degradation from current measurements and projected future growth of outdoor U-NII-1 access points. The impact on Globalstar user geographic service availability is described in Section 6.6. The measured noise rise of 1 ± 0.5 dB (1.8 ± 0.8 dB in 5170-5250 MHz) is seen to cause a 3% decrease in CDMA capacity and 1.5% decrease in RF power capacity. Both of these degradations exceed the 1% recommended impact limit in ITU-R Recommendation S.1427. As also described in this section, the degradation to Globalstar's MSS operations will likely increase significantly given the expected rates of growth for U-NII-1 access point deployments in the U.S.

6.1 Assessment of Interference Effects

Interference on the satellite feeder uplink from outdoor U-NII-1 access points affects MSS system capacity and service in more than one way. The following subsections assess these effects on system capacity and the demands on the satellites' limited transmitter power.

ITU-R Recommended Limits

ITU-R Recommendation S.1427-1 (2006) recommends assessment of interference based on the increase in satellite noise temperature ($\Delta T_{satellite}/T_{satellite}$). This is directly related to the noise rise, in accordance with the following formula: Noise-Rise-dB = 10 $log_{10}(1 + \Delta T_{satellite}/T_{satellite})$.

S.1427 also recommends that $\Delta T_{satellite}/T_{satellite}$ should be less than 3%, or the noise rise should be less than 0.13 dB. This can also be stated in terms of the I/N ratio of -15 dB.

S.1427 further recommends that any reduction in available satellite capacity be 1% or less.

S.1427 also states that aggregate long-term interference refers to interference at the satellite from all the U-NII-1 access point devices in view from the satellite.

6.2 Relationship Between Uplink and Downlink Degradation

The feeder uplink noise rise due to the aggregated interference of outdoor U-NII-1 access points can be used to calculate the degradation in carrier-to-noise ratio experienced on the satellite-to-mobile user device link, through the following relationship in equation 5 for satellites that act as repeaters.[38]

$$\left(\frac{C}{N}\right)_{ovr} = \left[\left(\frac{C}{I_{up}+N_{up}}\right)^{-1} + \left(\frac{C}{N_{down}}\right)^{-1}\right]^{-1} \qquad \text{Eq. 5}$$

In equation 5, N_{up} and N_{down} are the noise powers in the satellite feeder uplink and downlink, respectively, and I_{up} is the level of interference in the satellite feeder uplink generated by the outdoor U-NII-1 access points. $(C/N)_{ovr}$ is the overall carrier-to-noise ratio experienced at the mobile satellite system user device. For the MSS feeder uplink, a baseline $(C/N)_{up}$ of 19.9 dB is used, based on Globalstar-provided satellite parameters.

Figure 18 below is a plot of the degradation to the downlink $(C/N)_{ovr}$ caused by noise rise on the uplink. The graph shows the change in C/N in dB on the left scale, and the change in noise temperature (ΔT) on the right scale. Note that dBs are logarithmic while ΔT is linear so the curves do not exactly overlap. The change in the downlink is used in calculations in Sections 6.3 and 6.4.

[38] *See Satellite Communication Systems*, p. 117, M. Richharia, McGraw Hill, Second Edition, 1999.

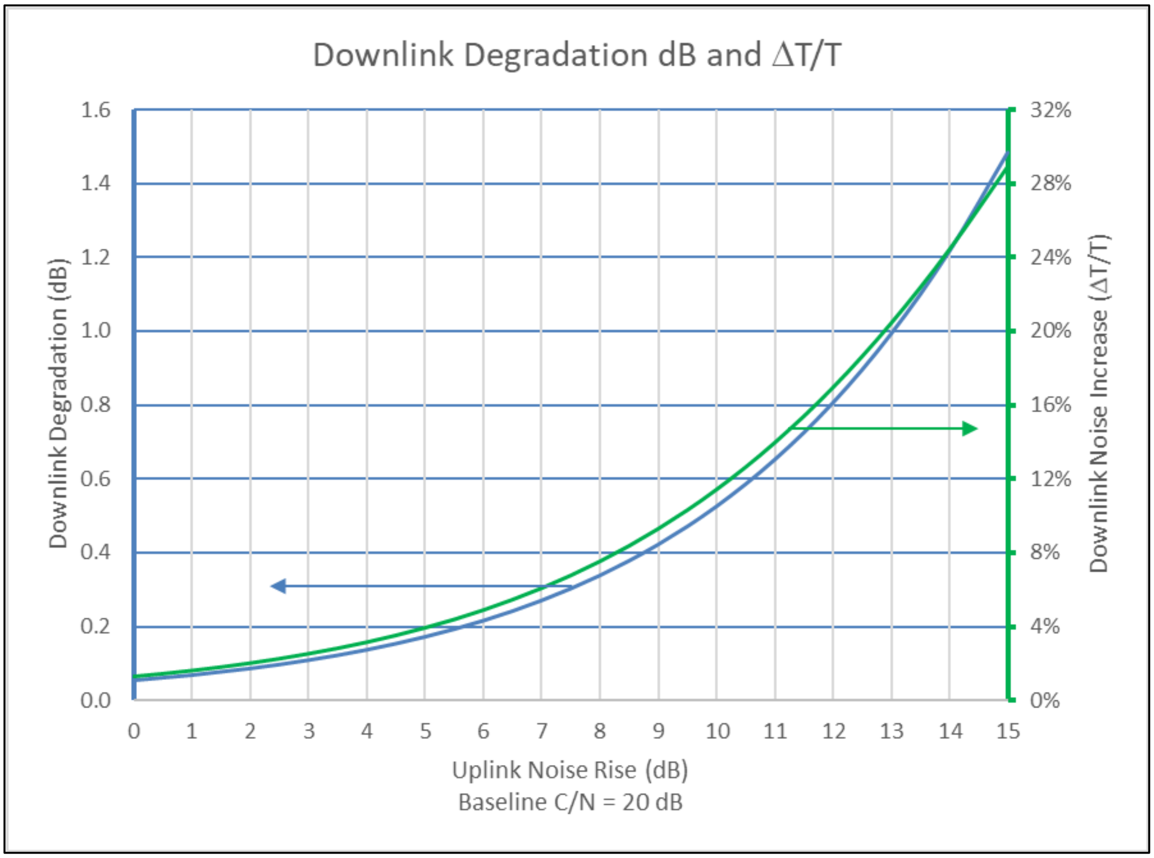

Figure 18: Downlink Degradation Due to Uplink Noise Rise

6.3 Impact on Globalstar CDMA Capacity

The capacity of the CDMA channels utilized by Globalstar in the satellite-to-user terminal communication links is limited by the inherent interference that exists between the CDMA co-channel and adjacent-channel users on those channels. Appendix C describes in greater detail the nature of the CDMA co- and adjacent-channel interference inherent in the Globalstar network. Given (1) the characteristics of CDMA and (2) the relationship between the satellite feeder uplink and downlink signal-to-noise analyzed above in Section 6.2, it is possible to assess the CDMA capacity degradation to Globalstar satellite-to-user handset communication channels as a result of noise rise on the satellite feeder uplink.

Since the CDMA downlink transmit power available at the satellite has a finite limit, degradation in the overall Globalstar downlink CDMA channels caused by aggregated U-NII-1 access point noise on the feeder uplink cannot be mitigated without impacting either the CDMA capacity or the communication link margin needed to provide the desired geographic coverage reliability and availability. In order to estimate the impact of overall downlink channel degradation on MSS performance, we assume the designed level of MSS geographic coverage reliability and link margin are maintained. Using the CDMA capacity relationships, we calculate the overall increase in downlink interference due to unlicensed access point transmissions in MSS feeder uplink spectrum; this feeder uplink noise must be compensated for with a corresponding reduction in the inherent CDMA co-channel and adjacent channel interference on the downlink. Since the inherent CDMA co-channel and adjacent channel interference is directly related to the number of co-channel and adjacent channel users, the capacity reduction for the CDMA downlink can be calculated. The capacity reduction is equivalent to a reduction in the number of simultaneous active CDMA users needed to maintain acceptable $Eb/(No+Io)_{ovr}$ on the downlink, where Io is the resultant total interference inherent to CDMA, plus the interference due to outdoor U-NII-1 access points.

6.3.1 Approach

The approach to determining the impact of outdoor U-NII-1 access point interference on CDMA capacity is as follows:

1. Calculate the <u>Increase</u> in interference on the overall MSS downlink.

   The additional interference term in the MSS uplink resulting from aggregated outdoor U-NII-1 access point interference degrades the $Eb/(No+Io)_{ovr}$ of the downlink as experienced at the MSS handheld receiver. Starting with equation 5 in Section 6.2, the degraded $Eb/(No+Io+Ia)_{ovr,deg}$ is calculated in equation 6 using the relationship, where Ia is the additional interference term[39]:

$$\frac{Eb}{N_0+I_o+I_a}_{ovr,deg} = \left[\left(\frac{Eb}{N_0+I_o+I_a}\right)_{up}^{-1} + \left(\frac{Eb}{N_0+I_o}\right)_{dn}^{-1}\right]^{-1} \qquad \text{Eq. 6}$$

2. Calculate the corresponding <u>Decrease</u> in inherent interference in the MSS CDMA downlink required to compensate for the overall Noise Rise caused by the Wi-Fi access points in the Uplink.

   The CDMA channels on the overall satellite-to-handheld downlink require a minimum overall $Eb/(No+Io)_{MIN,ovr}$ prior to any additional coherent combining receiver gain, to maintain acceptable bit error rate and user performance after combining is taken into account. In this equation, Io is the inherent interference spectral density resulting from the sum of intra-beam and adjacent beam co-channel MSS CDMA users. Since the $Eb/(No+Io)_{ovr}$ value has been degraded due to the addition of additional unlicensed access point interference, resulting in $Eb/(No+Io+Ia)_{ovr}$, Io_{dn} must be reduced to $Io_{dn,red}$ to maintain the value $Eb/(No+Io)_{MIN,ovr}$ required for acceptable communications performance. That is,

$$\frac{Eb}{N_0+I_o}_{MIN,\ ovr} = \left[\left(\frac{Eb}{N_0+I_o+I_a}\right)_{up}^{-1} + \left(\frac{Eb}{N_0+I_{o,red}}\right)_{dn}^{-1}\right]^{-1} \qquad \text{Eq. 7}$$

[39] Id.

where $Eb/(No+Io)_{MIN,ovr}$ is taken before any coherent combining. The individual values for No, Io, and Ia are known for the uplink and downlink, along with the value $Eb/(No+Io)_{MIN,ovr}$. Therefore $I_{o,red,dn}$ can be calculated for values of I_a -- corresponding to uplink interference from the access points -- as follows:

$$\left(\frac{E_b}{N_o+I_{0,red}}\right)_{dn} = Incr \times \left(\frac{E_b}{N_o+I_o}\right)_{dn} \qquad \text{Eq. 8}$$

or,

$$I_{0,red} = \frac{1}{Incr} I_o + \left(\frac{1}{Incr} - 1\right) N_o \qquad \text{Eq. 9}$$

where *Incr* = the fraction increase in downlink $Eb/(No+Io)_{dn}$ needed to compensate for the degraded uplink and maintain the overall $Eb/(No+Io)_{MIN,ovr}$, before any coherent combining.

3. Calculate the MSS downlink capacity decrease due to the necessary decrease in Inherent CDMA Interference.

Since the downlink CDMA protocol used in the MSS network is based on the terrestrial CDMA standard, an analysis based on the approach used to estimate terrestrial CDMA capacity can be utilized to determine capacity degradation in the mobile satellite CDMA downlink.[40] The overall $Eb/(No+Io+Ia)_{ovr}$ degradation at the mobile satellite receiver due to unlicensed access point interference in the MSS feeder uplink (assuming the MSS satellite parameters below in Table 3) is used to calculate the capacity degradation.

Since I_o and $I_{o,red}$ represent the sum of the co-channel user powers on the CDMA downlink, the reduction in interference power is directly proportional to the reduction in CDMA subscriber capacity. This results from the fact that CDMA capacity on the downlink is related to the interference generated by co-channel downlink users.

[40] *Introduction to Spread Spectrum Communications*, R. Peterson, R. Ziemer, and D. Borth, Prentice Hall, 1995.

Table 3. Globalstar CDMA Parameters

Ref.	Parameter			Note
	CDMA Forward Link Budget (satellite upink--> downlink to handset)			
A	Uplink Eb/(Io+No)	19.9	dB	Globalstar parameter
B	Rx signal/user/satellite	-168	dBW/1.23 MHz	Globalstar parameter
C	Log Bandwidth	60.90		
D	Rx signal density	-228.90	dBW/Hz	
E				
F	Downlink No (=kT)	-203.9	dBW/Hz	Globalstar parameter
G	Avg data rate (2400 bps)	33.80	dB bit/sec	Globalstar parameter
H	Eb/No = (B - F - G)	2.10		
I				
J	CDMA Downlink Interference Io per chl	-148.7	dBW	Globalstar parameter
K	Downlink Io density	-209.60	dBW/Hz	
L	Downlink No + Io	-202.9	dBW/Hz	
M	Down link Eb/(No+Io)	1.06	dB	Globalstar parameter
N	Overall Eb/(No+Io) [= Overall Eb/(No+Io) Baseline Required]	1.01	dB	Globalstar parameter
O	Coh combining gain (user handset)	2.5	dB	Globalstar parameter
P				
Q	Resulting Overall Eb/(Io+No) [= M+O (after coh comb)]	3.56		Globalstar parameter
R	Overall Eb/(Io+No)MIN needed, after coh comb	3.5		Globalstar parameter

A plot of Globalstar's relative MSS capacity (capacity degradation) based on feeder uplink noise rise due to aggregated outdoor U-NII-1 access point interference is shown in Figure 19. It is seen that feeder uplink noise rise values as small as 1-2 dB create noticeable decreases in CDMA capacity for the MSS channels in the frequency region 5170-5250 MHz. These decreases exceed the 1% limit in ITU-R Recommendation S.1427.

Also shown in Figure 19 is the number of outdoor access points, operating in compliance with FCC regulations, that corresponds to certain noise rise values, based on the relationship in Figure 14. The access point antennas were assumed to be omni-directional with transmit duty cycles of 10% and 20%, reasonable busy-period values. One million access points with a 10% duty cycle or 500 thousand access points with a 20% duty cycle would produce the noise rise value of 1.8 dB at 5170-5250 MHz, consistent with the 1 ± 0.5 dB noise rise measured by Globalstar's satellites over North America at 5096-5250 MHz. In June 2017, this noise rise was therefore producing a CDMA capacity reduction of 2-3%. As noted in Section 5.3.1, other combinations of access point numbers and duty cycle values could produce the noise rise being experienced by Globalstar's satellites providing service over the United States. In October 2017, the 3.3 dB noise rise in 5170-5250 MHz was doubling the CDMA capacity reduction to 5-6%.

As described in Section 5.3.3, industry information indicates that, overall, wireless LAN access point deployments are likely to increase at a rate of 35-43% per year. If outdoor deployments in the U-NII-1 band increase at these same rates, the number of outdoor U-NII-1 access points will increase to between 4.5 and 6 million from the base of one million access points at U-NII-1. For a 10% average AP duty cycle, 4.5 million and 6 million outdoor U-NII-1 access points would cause 13% and 19% degradations, respectively, to Globalstar capacity in the CDMA channels in the large geographic area covered by spot beams 0-7 in Figure 4. If the average AP duty cycle reaches 20%, the capacity degradations would be 25% to 35%. These significant decreases in capacity far exceed the recommended 1% limit in ITU-R Recommendation S.1427.

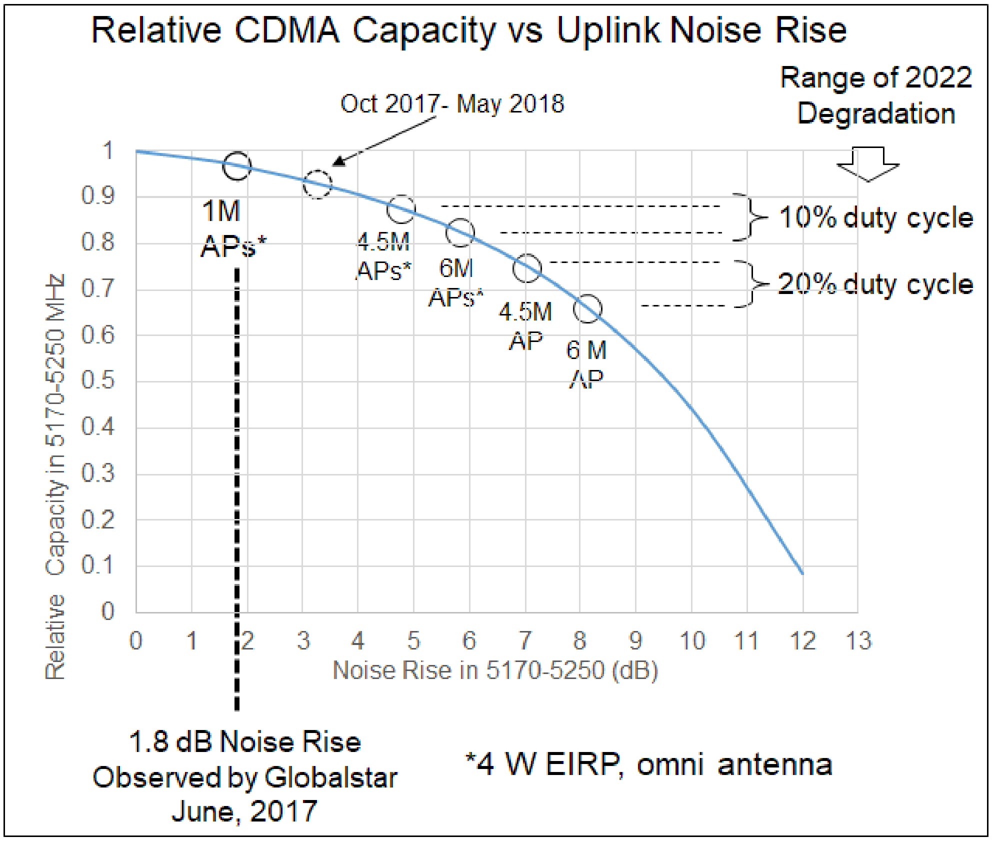

Figure 19: Relative Globalstar CDMA Capacity in Spot Beams 0-7 as a Function of Uplink Noise Rise Due to Aggregated Wi-Fi access point Interference, 2017-2022

6.4 Impact on Satellite RF Power Capacity Available

The previous section demonstrated the relationship between feeder uplink noise rise and reduced traffic capacity as a result of increased interference to the Globalstar CDMA channels. The introduction of additional interference due to the presence of outdoor U-NII-1 access points in the MSS feeder uplink, however, also has a significant impact on the amount of satellite RF power available for users' communications. (At any given moment in time, satellite RF power is fixed and finite.) In this section, the impact of Wi-Fi access point interference on available satellite RF power is analyzed. The following factors are addressed: 1) additional power consumed by amplification and retransmission of the feeder uplink Wi-Fi access point interference; 2) increase in power in CDMA overhead (supervisory) channels needed to maintain the signal-to-noise-plus-interference ratio necessary for successful communications; 3) the transmitted power increase needed to maintain the overall signal-to-noise-plus-interference ratio of the user communications channels at the handheld device to maintain geographic service availability and prevent an increase in failed call attempts and dropped calls.

The satellite system cannot avoid the power consumption resulting from the amplification of outdoor U-NII-1 access point interference on the MSS feeder uplink. Since the CDMA downlink user channels employ closed loop power control, if the link quality is degraded by interference, then the user transmit power is increased to maintain the user call quality. If the satellite-to-user CDMA overhead power is increased to overcome the signal-to-noise-plus-interference degradation and maintain geographic service availability, then the satellite power available for users is further reduced and degraded. This reduction in available satellite RF power "steals" power that would otherwise be used to maintain user communications, and in turn reduces the number of users that can be supported. The capacity reductions described here are alternative effects to the CDMA-based capacity degradation previously discussed in Section 6.3. The power consumption from amplification of the unlicensed access point interference and the resulting automatic decrease in user RF power are always incurred. This is a base, inherent level of capacity reduction that represents at least some portion of the capacity impact described in Section 6.3

Table 4 below illustrates the method for calculating the impact of access point interference on available satellite power, for a feeder uplink noise rise of 10 dB due to outdoor U-NII-1 access point interference. The method is as follows:

1. Rows A through E provide the satellite uplink operational parameters provided by Globalstar in its Federal Communications Commission filing,[41] together with an uplink received interference power due to aggregated U-NII-1 access point interference of -132 dBW/MHz (Row B), which causes a 10 dB noise rise.
2. Applying the transponder gain of 122.7 dB, the resulting amplified downlink interference power spectral density is calculated as 20.1% of available power (row L). This is the additional satellite power consumed (wasted) by amplification of the access point interference.
3. Rows N through AA use Globalstar satellite characteristics from the Federal Communications Commission filing[42] to calculate the 2.8% of additional overhead power consumed (wasted) by increasing the CDMA overhead transmitted power to compensate for the degraded signal-to-noise-plus-interference caused by the unlicensed access points. In the Globalstar satellites, 15% of the CDMA downlink power is consumed by pilot, synchronization, and paging channels.[43]
4. The total power wasted merely due to amplifying the feeder uplink interference is 28.7% of the nominal Globalstar satellite transmit power available in Row W.
5. Row X takes into account the additional 0.55 dB downlink transmitted power required to compensate for the degraded overall signal-to-noise plus interference caused by the

[41] *See Comments of Globalstar*, ET Docket No. 13-49, May 28, 2013, accessed at https://ecfsapi.fcc.gov/file/7022418837.pdf (*Globalstar Filing.)*

[42] Id.

[43] *See CDMA2000 Evolution, Kamran Etemad, John Wiley and Sons, 2004, p. 57.* In a CDMA downlink, the total transmitted power is divided among overhead channels and user traffic channels. The overhead channels consisting of pilot, sync, and paging channels take a static allocation of transmitted power which does not change with the number of users. In a terrestrial IS-95 CDMA network, the overhead consumes 25-30% of maximum available power. In the Globalstar system, the overhead is 15% of the available transmit power.

aggregated outdoor U-NII-1 access point interference.[44] This is 12% of the transmit power available.

The overall lost power due to amplifying the interference and increasing the transmit power to compensate for degraded downlink is therefore approximately 40% of available transmit power. (Rows Z and AA) This loss of power causes degradation to the geographic coverage area of the satellite, accompanied by significant increases in failed call attempt and dropped calls when there are a large number of active users on the system, such as during hurricanes and other catastrophic events taking place over a large geographic area.

Table 4. Impact of Access Point Interference on Satellite RF Power

Ref.	Parameter	Value		Note
A	Uplink Noise Power Spectral Density	-141.5	dBW/MHz	kTB for T = 509.3 deg K
B	Received Interference Power Due to RLANs	-132.0	dBW/MHz	
C	Noise Rise on Uplink	10.0	dB	
D	Satellite Uplink Receive Antenna Gain	6.37	dB	LEO-D provided value
E	Satellite RX Line Loss	-2.60	dB	LEO-D provided value
F				
G	Received Wi-Fi interference power@LNA = B+D+E	-128.23	dBW/MHz	
H	Nominal Transponder Gain (includes RX and TX Line Losses)	122.7	dB	LEO-D provided value
I	TX Line loss	-2.10	dB	LEO-D provided value
J	WiFi interference power generated by satellite PA = G+H-E-I	-0.83	dBW/MHz	
K	WiFi interference power per MHz generated by satellite	0.83	Watts/MHz	
L	Total WiFi interference power generated by satellite (53 channels)	20.1%	watts	percent of nominal RF power
Q	CDMA Downlink Overhead as % of Sat Peak Power	15%		LEO-D provided value
R	Satellite power overheads (CDMA) without Interference	20.2%		percent of nominal RF power
S	New power overhead w. interference (R + 0.55 dB interference)	23.0%		percent of nominal RF power
T	Total Nominal Satellite power (including eclipse)	100%		
U	Available Satellite Power for RF transmission with interference = T-S	77.0%		percent of nominal RF power
V	Wasted Available power due to interference = L + S-R	22.9%		percent of nominal RF power
W	Wasted Available power due to interference =V / (T-R)	28.7%		
X	Additional % power to increase transmit power by (0.55 dB)	12%		From Figure 15
Y	Additional power to increase transmit power = X *(T -R)	9.5%		percent of nominal RF power
Z	Total lost power available for RF (user transmissions) = V+Y	32.4%		percent of nominal RF power
AA	Total lost power available for RF (user transmissions) =Z / (T-R)	40.5%		60% Capacity
AB	Net RF power available for user transmissions (1.0 - L -S -Y)	47.4%		

[44] Taken from Figure 18, for an uplink noise rise of 10 dB.

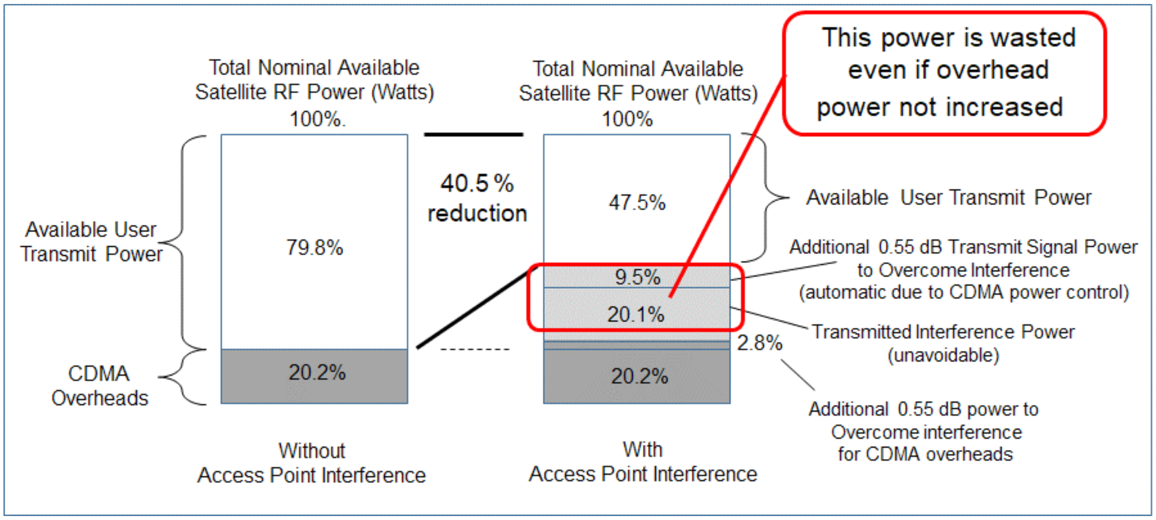

Figure 20: Degradation in Satellite RF Power Available to Users Due to Access Point Interference

A comparison of the Globalstar satellite power allocation budget without and with unlicensed access point interference that creates a 10 dB feeder uplink noise rise is illustrated in Figure 20. The available transmit power is reduced from 79.8% to 47.5% of nominal RF PA capacity, a significant reduction of 40.5%. The reduced power available for downlink transmissions at 2483.5-2500 MHz directly reduces the number of users that can be supported by the satellite.

If the degradation in CDMA overhead signal-to-noise ratio is *not* compensated for by an increase in transmitted CDMA overhead power, then an unavoidable power and capacity reduction of 37% is still incurred because of (1) the downlink amplification of the increased interference present on the feeder uplink and (2) the automatic power increase in the user channels.[45] This capacity reduction causes increased "system busy" indications to Globalstar users. The amount of additional RF power needed to maintain the geographic service availability is another 3.5% of RF power and capacity lost.

This calculation of the unlicensed access point interference on satellite RF power does not take into account the time-varying nature of the power available at the satellite due to the sun being eclipsed at the satellite by the earth for 35 minutes of its 114 minute orbital period (30% of the time). If the peak interference and concomitant wasted RF power were to occur when the satellite is eclipsed, satellite operation could be further compromised.

[45] Since the Globalstar CDMA downlink employs closed-loop power control, the downlink power to the users is automatically increased to compensate for the increased overall interference-plus-noise in order to maintain user link quality. As the number of active satellite users increases, at some point the satellite cannot supply enough additional power to overcome the AP interference. The additional RF power used to compensate for increased interference is power that is wasted and not available to MSS users.

Variation of Impact as a Function of Uplink Noise Rise

Using the approach described above, Figure 21 illustrates the relative satellite RF power available, corresponding to relative user capacity, as a function of the feeder uplink noise rise caused by aggregated outdoor U-NII-1 access point interference.

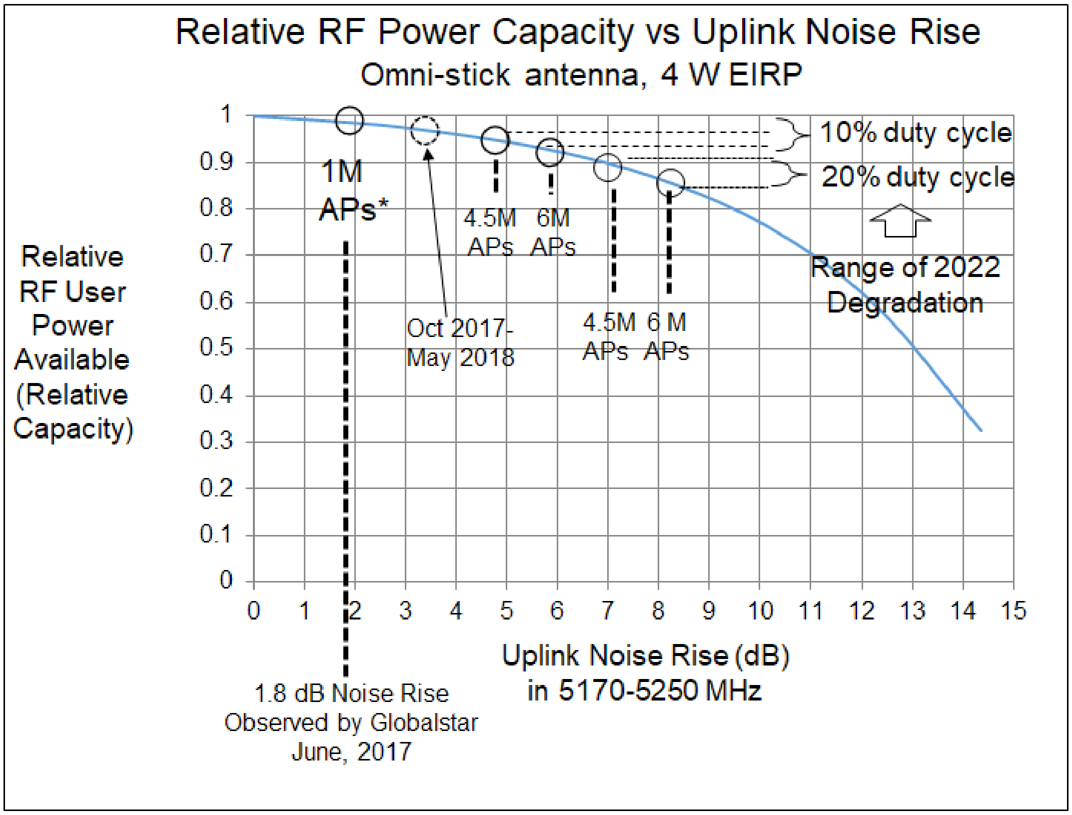

Figure 21: Relative RF Power Capacity Due to Power Consumed by Wi-Fi Access Point Interference

Also shown in Figure 21 are the number of outdoor access points, operating in compliance with FCC regulations, that correspond to certain noise rise values, based on the relationship in Figure 14. The access point antennas were assumed to be omnidirectional with access point duty cycles of 10% and 20%, reasonable busy-period values. One million access points with 10% duty cycle or 500 thousand access points with 20% duty cycle would produce the noise rise value of 1.8 dB at 5170-5250 MHz, consistent with the 1 ± 0.5 dB noise rise measured by Globalstar's satellites over North America at 5096-5250 MHz in June 2017. This noise rise was therefore producing an RF power amplifier capacity reduction of 2% in June 2017. As of October 2017, the 3.3 dB noise rise at 5170-5250 MHz, consistent with the 2 ± 0.5 dB noise rise measured by Globalstar at 5096-5250 MHz, was producing an RF PA capacity reduction of approximately 4%.

As described in Section 5.3.3, industry information indicates that overall wireless LAN access point deployments are likely to increase at a rate of 35-43% per year. If outdoor deployments in the U-NII-1 band increase at these same rates, the number of outdoor access points will increase to between 4.5 and 6 million, from the base of one million access points in U-NII-1. For a 10% average access point duty cycle, 4.5 million and 6 million outdoor access points in the U-NII-1 band would cause 6% and 8% degradation, respectively, to Globalstar RF power amplifier capacity in the CDMA channels in the large geographic area covered by spot beams 0-7 in Figure 4. For a 20% average access point duty cycle, 4.5 and 6 million outdoor access points would cause 10% and 15% reductions in RF power amplifier capacity. These significant decreases in capacity far exceed the recommended 1% limit in ITU-R Recommendation S.1427.

6.5 Impact on Globalstar Geographic Service Availability

The previous sections considered the negative impact of feeder uplink interference due to outdoor Wi-Fi access point wireless operations on Globalstar downlink capacity in the 2.4 GHz band, assuming no change to user quality of service as measured by geographic service availability and successful call rate. In the previous Section 6.3 analysis, the quality of service is maintained by decreasing user capacity and corresponding CDMA inter- and intra-beam interference in the 2.4 GHz downlink, in order to compensate for the increased feeder link interference. In the previous Section 6.4 analysis, the geographic availability of service is maintained by directly increasing the CDMA overhead transmitted power, which also reduces capacity since less power is available to distribute among the users. The unavoidable negative impact on available RF power (and capacity) was also analyzed for the case where CDMA overhead power was not adjusted, allowing the geographic service availability to degrade.

On the other hand, if the negative impact of additional uplink interference is not compensated for, and instead user capacity is maintained, then the overall downlink Eb/(No+Io) for the CDMA paging, synchronization, and pilot channels received by the Globalstar handhelds will be degraded due to the interference power of the unlicensed access points. This degradation will cause a reduction in the signal-to-noise-plus-interference power required to compensate for statistical variations in received signal strength due to signal shadowing, resulting in a) an increase in the geographic area outages (increase in “no service available” indication by the user); b) an increase in dropped calls; and c) an increase in failed call attempts. Previous studies of non-geostationary satellite coverage can be used to estimate the effect on Globalstar coverage reliability.[46] An overall downlink degradation of 0.5 to 1 dB, which is the expected range of the overall downlink degradation calculated in Tables 3 and 4, would increase service area outages by 5%, a noticeable amount. This is equivalent to decreasing the geographic availability of the Globalstar service by 5%.[47] This level of degradation would result in calls failing to be established where they otherwise would be successful without interference. This degradation has been confirmed by internal Globalstar network analysis modeling.

[46] *See* Giovanni E. Corazza and Francesco Vatalaro, “A Statistical Model for Land Mobile Satellite Channels and Its Application to Nongeostationary Orbit Systems,” *IEEE Transactions on Vehicular Technology*, Vol. 43, No. 3, August, 1994, Figure 1, p. 739.

[47] This reduction in geographic availability would encompass approximately 365,000 sq. km., since the area of the degraded spot-beams from Table 1 is 7,302,000 sq. km.

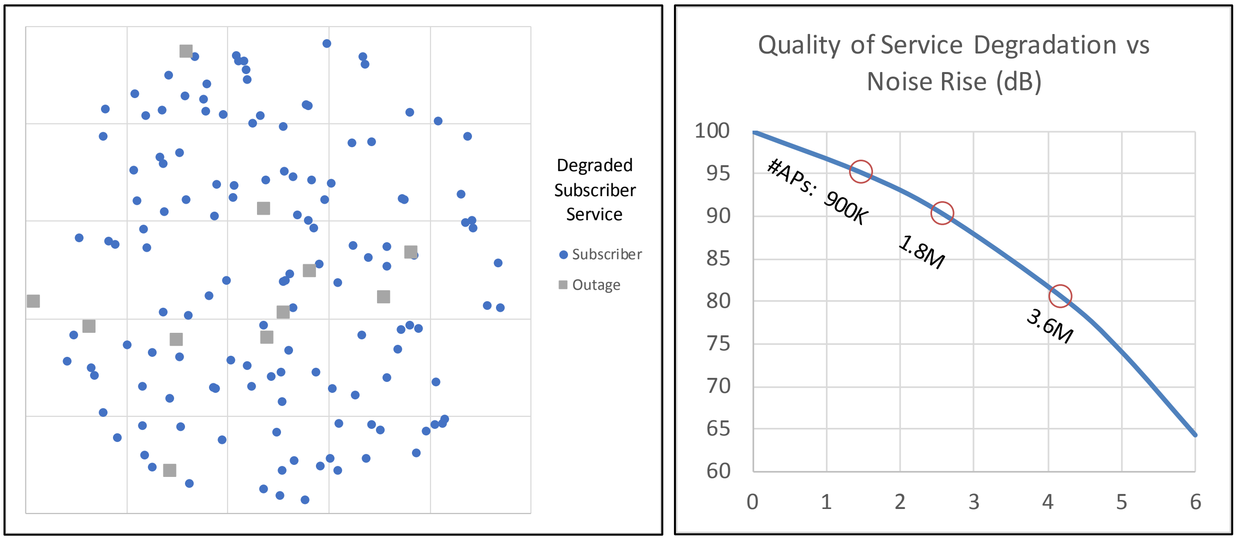

Figure 22: Qualitative Illustration of Impact of Degraded Signal-to-Noise-plus-Interference on Globalstar Downlink

Figure 22 above illustrates qualitatively the negative impact of degraded signal-to-noise-plus-interference on the Globalstar downlink, due to outdoor U-NII-1 access point interference to the MSS feeder uplink. The quality of service of the Globalstar satellite downlink beams is decreased, and there is an increase in the service outages within the beam footprint. An increase in service outages is experienced by the user as failed call attempts and dropped calls.

6.6 Real-World Impact on Globalstar Users

Analysis of the satellite traffic handled during actual, prior disaster events that resulted in large numbers of satellite users demonstrates the likely real-world user impact of interference in the event of similar catastrophic events, when life-critical emergency communications are needed. For example, during Hurricane Katrina in 2005, satellite traffic usage was logged at 78% of capacity in certain spot beams.[48] Figure 19 above shows that if the noise rise due to U-NII-1 interference was 7 dB in 5170-5250 MHz (5 dB as measured at the satellite in 5096-5250 MHz), then the number of simultaneous users would be limited to 75% of satellite capacity, with the result that the number of simultaneous users logged during Katrina would not have been successfully served. Additional users beyond 75% of capacity would degrade service for all users, resulting in an increase in dropped calls, geographic coverage holes, and failed call attempts. Since 2005, the number of voice and data subscribers on Globalstar's network has increased. The introduction of new two-way devices and voice and data services in 2018 will create further subscriber growth, such that traffic demand in Katrina-type events can be expected to increase beyond the level experienced in 2005. With peak traffic demand during disaster events expected to be greater than the 2005 level of 78%, a 5 dB satellite measured noise rise would deny the expected geographic coverage and acceptable

[48] "Globalstar LLC-Supplemental Information," submitted to the FCC by William F. Adler, March 16,2006, pursuant to a request made at the *Hurricane Katrina Independent Panel*, Federal Communications Commission, March 16, 2006.

service to life-critical satellite users. Figure 17 shows that a 7 dB noise rise due to Wi-Fi access points (5 dB as measured at the satellite in 5096-5250 MHz) could occur as early as 2021.

7. Impact to Globalstar as a Function of the Number of Wi-Fi Access Points Deployed and Access Point Duty Cycle

Section 4 described how the number of outdoor U-NII-1 access points increased the noise rise in Globalstar's feeder uplink spectrum. Section 6 described how noise rise affected CDMA capacity and RF power capacity as functions of the noise rise. In this section, the results are merged so that the degradation to the system is described as a function of the number of APs and their duty cycle. While Section 4 averaged noise rise for all types of AP antennas, including the omni-directional stick antenna, a directional panel antenna, and a high gain dish antenna, this section will only consider degradation from the omni-directional stick antenna. This is the most benign of the three antennas with respect to interference. The aggregate interference of outdoor U-NII-1 access points with omni-stick antennas is 3 dB below the aggregate interference computed in Section 4, Table 2 for access points with a mix of antenna types.

7.1 CDMA Capacity Impact

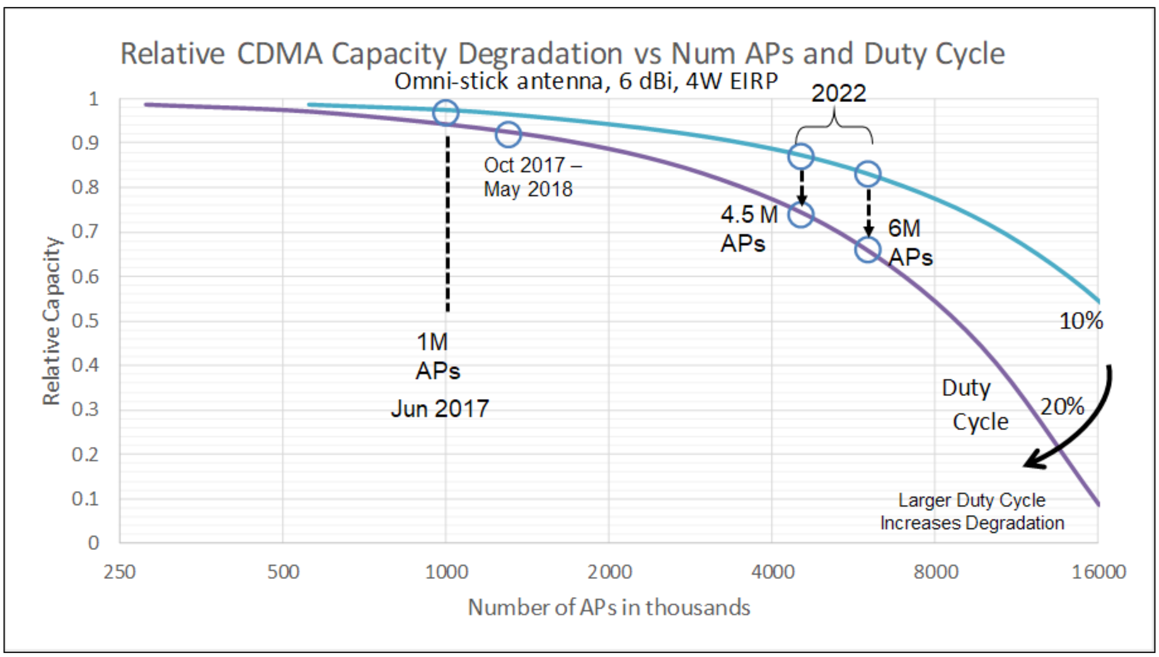

Figure 23: CDMA Capacity Degradation vs Number of APs

Figure 23 shows the relative CDMA capacity as the number of outdoor APs varies from 62,500 to 16 million. This is the same calculation as in Figure 19. In this case the noise rise in the 5170-5250 MHz band is computed as a function of the number of APs and the duty cycle. All of the curves start at 1.5% capacity degradation, exceeding the 1% limit from ITU-R Recommendation S.1427. From a base of one million outdoor access points deployed in 2017 operating at a duty cycle of 10% (consistent with Globalstar's noise rise measurements), the degradation will increase to 13% and

19% in 2022, assuming access point deployments of 4.5 or 6 million, respectively, based on the NCTA and Cisco reports. For access points with an average duty cycle of 20%, the degradation would be 25% to 35%, respectively. If ten million outdoor access points operating at a 10% duty cycle are eventually deployed in the U-NII-1 band, Globalstar would suffer over a 30% degradation in capacity in the affected spot beams in Figure 4.

7.2 RF Power Capacity Impact

Figure 24 shows the capacity degradation resulting from limitations on the available satellite RF power, similar to Figure 19 but scaled again according to the number of APs calculated to obtain the noise rise. The number of APs is calculated according to the power flux density at the satellite tabulated in Table 2 and graphed in Figure 8 at 100% duty cycle. The minimum degradation shown in all the curves in Figure 24 is a 1.2% decrease in RF power, exceeding the 1% limit specified by ITU-R Recommendation S.1427.

From a base of one million outdoor access points deployed in 2017 operating at a duty cycle of 10% (consistent with Globalstar's noise rise measurements), the degradation for access points with an average duty cycle of 10% will increase to 6% and 8% in 2022, assuming deployments of 4.5 or 6 million, respectively, based on the NCTA and Cisco reports. For access points with an average duty cycle of 20%, the degradation will increase to 10% and 15%, respectively, in the affected spot beams in Figure 4.

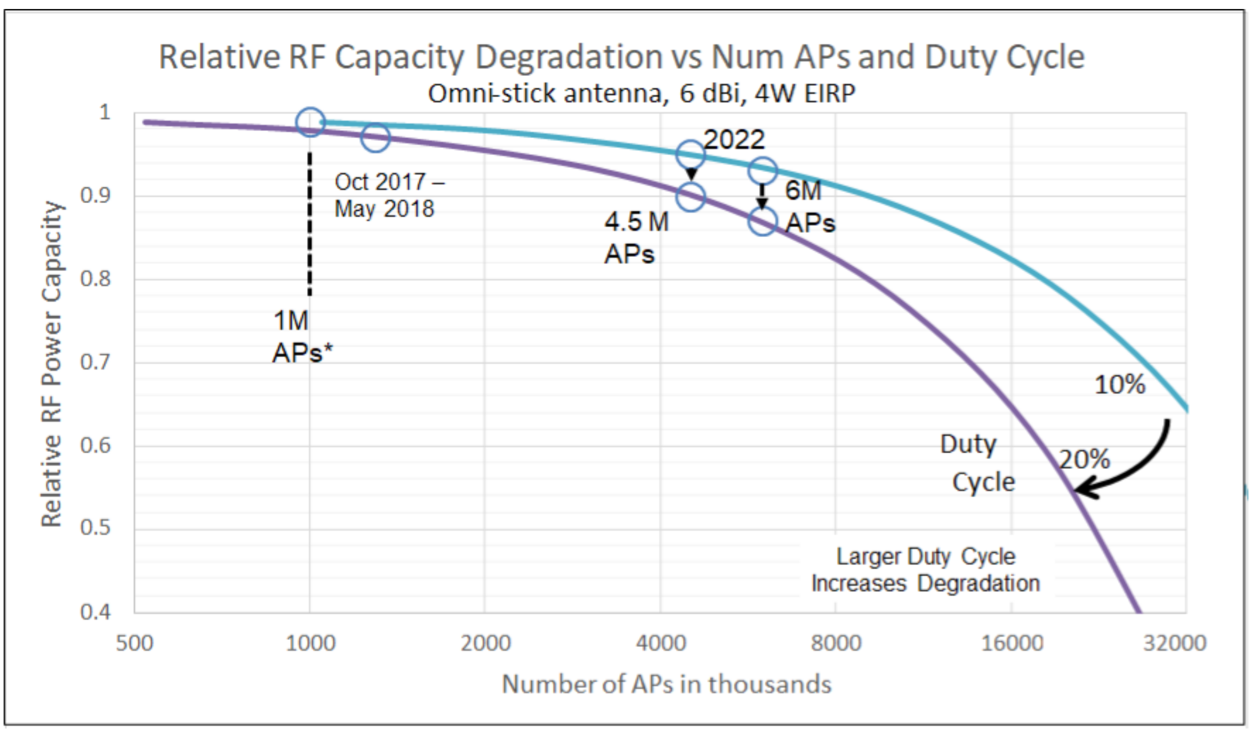

Figure 24: RF Power Capacity Degradation vs Number of APs

8. Sources of Noise Rise Other Than Carrier Wi-Fi

In addition to the interference caused by carrier-operated Wi-Fi access points operating in U-NII-1, other sources of the noise rise, both internal and external to Globalstar, were investigated. Internal sources are causes of a noise floor increase originating within the Globalstar satellite network. External sources are causes of interference outside of Globalstar's MSS system and the components of that system.

8.1 Sources Internal to Globalstar

Potential internal sources of the noise rise in Globalstar's feeder uplink spectrum are (1) change in the noise figure or operating parameters caused by satellite component variation or aging and (2) diurnal effects on satellite components.

8.1.1 Change in Satellite Components or Noise Figure Increase

Without variation, Globalstar's measurements show no change in the noise floor while the satellites are in view of blue ocean or the densely populated area of Europe. These results contrast with measurements over the United States, where a noise rise is observed. Unless there were interference sources external to the Globalstar satellite network, it is extremely unlikely that (i) the noise level measurements for multiple satellites would change over the U.S. but not elsewhere and (ii) these changes would occur during the course of a single satellite orbit, only minutes before or after the noise rise is observed over the United States.

Additionally, prior to launch, the components of the Globalstar transponders aboard all its satellites were accurately characterized for key operating parameters including linearity, bandwidth, and dynamic range. Provision for re-measuring and verifying component functionality is available while the satellites are in operation. These measurements, performed on a regular basis, have revealed that the transponders continue to operate within their designed specifications. Thus, it can be concluded that Globalstar's system component operations are not the cause of the noise rise in Globalstar's feeder uplink spectrum.

8.1.2 Diurnal Effects on the Satellite

Day-night effects can be ruled out as the cause of changes in the noise floor at the satellites. As indicated above, Globalstar's measurements show no change in the noise floor while the satellites are over blue ocean or over the densely populated area of Europe, while they do show a noise rise over the United States. Furthermore, the 2014 baseline noise floor measurements were made during daylight periods on earth.

8.2 Sources of Noise Rise External to Globalstar

8.2.1 Government Authorized Emitters

8.2.1.1 AeroMACS

The Aeronautical Mobile Airport Communication System (AeroMACS) provides wireless broadband communications for aircraft while on the ground at airports. AeroMACS is based on the IEEE 802.16e "WiMAX" standard, and is authorized to operate in the frequency band 5091-5150 MHz.[49]

Although AeroMACS is authorized to operate within Globalstar's feeder uplink spectrum, there are currently only two AeroMACS systems in trial operation in the United States, according to the Federal Aviation Administration ("FAA"): one at San Francisco International Airport and another at Hopkins International Airport in Cleveland, Ohio.[50]

Although we do not know the deployment parameters of the AeroMACS trial systems, the impact of AeroMACS can be assessed relative to outdoor Wi-Fi by assuming there are four high-power "macro-cell" base stations transmitting at 32 dBW EIRP (1500 Watts) at each airport, and comparing the interference generated by eight AeroMACS transmitters to the interference created by a large population of Wi-Fi access points. With the additional assumption that the antenna characteristics of the Wi-Fi APs and the AeroMACS base stations are similar, it is seen that eight AeroMACS transmitters generate the interference power of about 3000 4 Watt EIRP outdoor access points. The calculations and model in Section 4 above (Figure 8, for example) show that 3000 outdoor access points generate an insignificant noise rise, far below the 1 dB noise rise observed by Globalstar.

Therefore, it is extremely unlikely that the noise rise levels observed by Globalstar at its satellites are caused by AeroMACS operations.

8.2.1.2 Unmanned Aircraft Systems (UAS)

The standards for Unmanned Aircraft Systems ("UAS") are contained in RTCA DO-362. These standards provide for control of Unmanned Aircraft Systems in the frequency band 5030-5091 MHz. According to the FAA, there are several near standards-compliant systems being tested, and testing is being limited to 5030-5040 MHz.[51]

Because (i) the current UAS operations are outside of Globalstar's uplink spectrum at 5096-5250 MHz and (ii) the Globalstar satellite receiver front end RF filter significantly attenuates the UAS

[49] *AeroMACS*, WiMAX FORUM, accessed at http://wimaxforum.org/Page/AeroMACS
[50] This information regarding AeroMACS was provided to Globalstar by an official at the FAA.
[51] This information regarding UAS testing was provided to Globalstar by an official at the FAA on January 10, 2018.

transmissions that are 50 MHz out-of-band,[52] it is extremely unlikely that limited UAS testing is causing the noise rise observed by Globalstar.

8.2.2 Commercial Sources of External Interference

8.2.2.1 LTE-U and LAA Supplemental Downlink

2017 Assessment

3GPP, the standards body responsible for the LTE terrestrial broadband wireless specification, has designated Band 46 (which contains the U-NII-1 band) for supplemental downlink operations by carrier operators.[53] Carrier operations in Band 46 utilize either the LTE-U (LTE-unlicensed) or 3GPP based LAA (License Assisted Access) protocols. In the future, Band 46 supplemental downlink operations will most likely migrate to LAA.[54]

The figure below illustrates the overlap between Band 46 and Globalstar's feeder uplink. The ten 10 MHz LTE channels shown below potentially impact 138 of Globalstar's 208 user traffic channels on each satellite and the geographic service area of twelve of the sixteen downlink spot beams.[55] As seen in Figure 4, a significant portion of Globalstar satellites' service area is potentially impacted by Band 46 emissions.

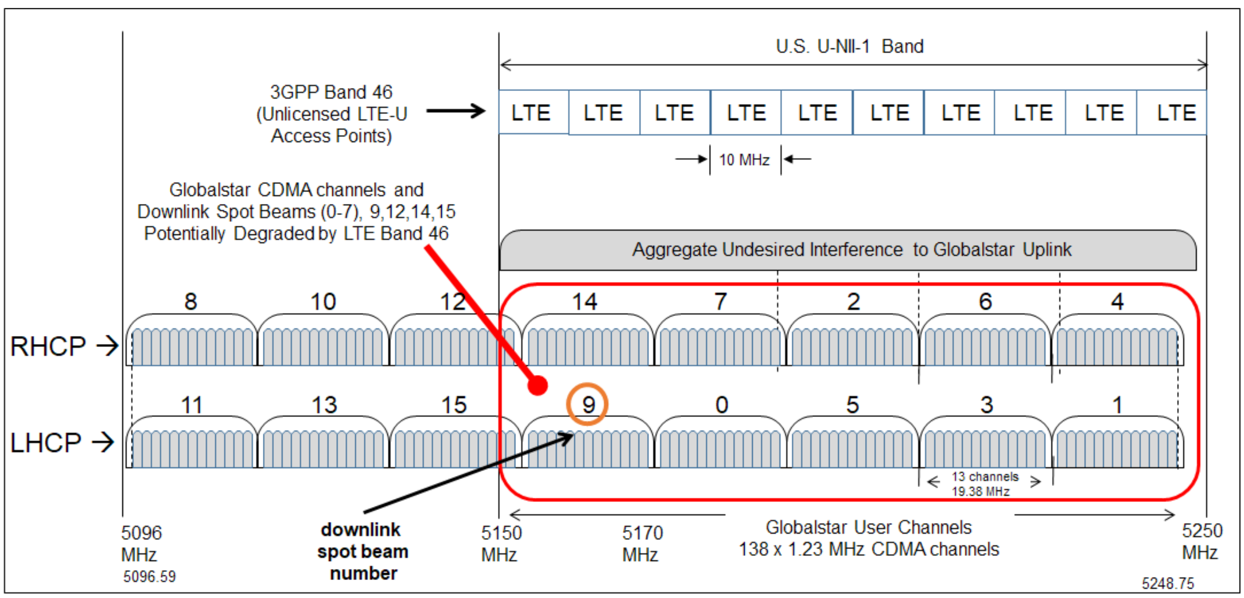

Figure 25: 3GPP Band 46 and Globalstar Feeder Uplink

[52] *Globalstar Noise Floor Measurement Report*.
[53] 3GPP Release 13, accessable at https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2411
[54] *See* https://www.fiercewireless.com/wireless/editor-s-corner-laa-s-uptick-was-lte-u-worth-hassle
[55] 20 MHz LTE channels are also specified in 3GPP Release 13.

To date, AT&T,[56] Verizon,[57] and T-Mobile[58] have conducted trials of LTE-U or LAA for supplemental downlink in the U-NII-1 band. Based on publicly available information for activity in 2017, trial operations in Band 46 have been limited in duration and geographic scope, occurring in only a few cities and involving less than 100 base station transmitter sites overall. In addition, these trials during 2017 utilized not only U-NII-1 spectrum, but also other U-NII frequencies in the 5 GHz band.

For these reasons, Band 46 operations are judged to be insufficient to contribute to the noise rise observed by Globalstar in 2017 since, as shown in Section 4, tens of thousands of outdoor U-NII-1 transmitters are required to generate even a small noise rise in Globalstar's uplink.

Future LTE Deployments in U-NII-1

In 2018, several cellular operators have deployed LTE-LAA utilizing Band 46 and announced plans for additional deployments in the future. AT&T for example, is currently serving four markets with LTE-LAA (Chicago, Indianapolis, Los Angeles, and San Francisco) and will soon add Boston, Sacramento, and McAllen, Texas.[59] AT&T's Chicago deployment consists of outdoor cells with coverage radii of 150-400 feet.[60] (See Figure 28 in Appendix B.) AT&T plans to deploy 4000 LTE-LAA sites in 2018-2019 in addition to the 200 already deployed in 2017.[61] T-Mobile plans to deploy 25,000 small cell LTE-LAA sites in the future.[62]

In anticipation of future Band 46 deployments and utilization, the Samsung Galaxy S8 smartphone is reported as supporting operation in Band 46.[63]

Band 46 extends from 5150-5925 MHz with the first of four sub-bands corresponding to U-NII-1, which overlaps Globalstar's fixed feeder uplink. While it is not known what frequency sub-band or bands the cellular operators plan to use for LTE, or what fraction of base stations will be deployed outdoors, future Band 46 LTE-LAA supplemental downlink deployment is a significant concern for Globalstar. Since supplemental downlinks are used to provide extra capacity needed for applications such as streaming video and other throughput-intensive applications, LTE-LAA in U-NII-1 will result in high levels of transmitter utilization, increasing the aggregate interference to Globalstar's MSS network beyond that projected if only Wi-Fi usage is considered. Significantly, the

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56 *See* http://about.att.com/story/lte_licensed_assisted_access_field_trials.html.
57 *See* https://www.rcrwireless.com/20170804/carriers/verizon-starts-nationwide-laa-deployment-tag4.
58 *See* https://www.tmonews.com/2017/06/t-mobile-laa-testing-lte-u-rollout/.
59 "AT&T expands '4G Evolution' to 117 new markets, adds LAA to 3 markets," *Fierce Wireless*, Apr 20,2018, accessed at https://www.fiercewireless.com/wireless/at-t-expands-5g-evolution-to-117-new-markets-adds-laa-to-3-more-markets.
60 "Exclusive: AT&T LTE Hits 537 Mbps in Chicago," *PC Mag*, March 29, 2018, accessed at https://www.pcmag.com/news/360113/exclusive-at-t-lte-hits-537mbps-in-chicago.
61 "AT&T says 6 GHz band key for FirstNet, 5G" accessed at https://www.fiercewireless.com/wireless/at-t-says-6-ghz-band-key-for-firstnet-5g.
62 "Speed tests show T-Mobile LAA surpassing 500 Mbps in New York City," *TmoNews*, March 5, 2018, accessed at https://www.tmonews.com/2018/03/speed-tests-t-mobile-laa-surpassing-500mbps-new-york-city/.
63 *See* https://www.tmonews.com/2017/06/t-mobile-laa-testing-lte-u-rollout/.

existence of devices in U-NII-1 using the 3GPP LTE standard were not foreseen or taken into account in the 2014 FCC Report and Order.

8.2.2.2 Wireless Internet Service Provider (WISP) Networks

According to the *2017 Broadband Wireless Association Industry Report*, Wireless Internet Service Providers (WISPs) most commonly use the following frequency bands: 500-700 MHz, 902-928 MHz, 2.4 GHz, 3.55-3.7 GHz, 5.15-5.85 GHz, 28 and 39 GHz.[64] The report states that the 5 GHz band is most commonly used by WISPs for fixed point-to-point operations which employ narrow-beam, highly directive antennas pointed toward the horizon. Given the highly directional nature of these operations and the relatively small number of WISP base station sites, it is highly unlikely that WISP operations have materially contributed to the noise rise measured by Globalstar at its satellites.

8.2.3 Consumer Access Points

Since the 2014 FCC order authorizing outdoor and higher-power (4 W EIRP) access points in U-NII-1, consumer electronics manufacturers have responded with a broad array of devices marketed as "dual-band" and "tri-band" wireless routers," which are access points capable of operating in both the 2.4 GHz band and the 5 GHz unlicensed band (including U-NII-1). Appendix F contains a list of the "Best Wireless Routers of 2018," as assessed by PCMAG.[65] These routers are identified as being readily available on the web or in retail outlets. It is seen that all ten routers, ranging in price from $60 to $412, support IEEE 802.11ac, which requires the capability to operate in the U-NII-1 band and elsewhere at 5 GHz.

Market research indicates that for the years 2014-2017, 8.95 million 802.11ac wireless routers capable of operating in U-NII-1 were sold in the U.S.[66] Although the number of "self-provisioned" U-NII-1 access points purchased, installed, and operated by consumers is large and these access points likely contribute to the noise rise observed by Globalstar to some marginal degree, most of these consumer devices are installed and operated indoors, as indicated by their form factor and required operating environment. Given the indoor operation of these access points and the fact that consumer wireless routers also operate in the 2.4 GHz band and on other 5 GHz spectrum, it is highly unlikely that self-provisioned consumer access points are currently a material contributor to the noise rise in Globalstar's feeder uplink spectrum.

8.2.4 Summary of Potential Other Sources of Interference to Globalstar

It is highly likely that the recent noise rise in Globalstar's feeder uplink spectrum is due to the large number of outdoor U-NII-1 access points that have been deployed by cable operators around the United States. It is highly unlikely, meanwhile, that other U-NII-1 equipment and devices deployed

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[64] *2017 Broadband Wireless Industry Association 2017 Report*, p. 13, The Carmel Group, accessed at http://www.wispa.org/Portals/37/Docs/Press%20Releases/2017/TCG's_2017_BWA_FINAL_REPORT.pdf.
[65] *See Best Wireless Routers of 2018*, PCMAG, Feb. 13, 2018, accessed at https://www.pcmag.com/article2/0,2817,2398080,00.asp.
[66] "Global Wireless Router Market: 2017-2023," Mordor Intelligence, Inc.

by governmental bodies, other commercial entities, and consumers are material contributors to the noise rise detected by Globalstar's measurements in 2017-2018.

9. Conclusions

Interference in the 5170-5250 MHz band in Globalstar's feeder uplink spectrum has caused a 1 ±0.5 dB noise rise in the 5096-5250 MHz band at Globalstar's satellites, exceeding ITU-R recommended limits. Governmental, commercial, and consumer U-NII-1 deployments have been investigated as potential causes of this noise rise. These investigations have resulted in the conclusion that the noise rise at 5096-5250 MHz can be attributed to cable operators' deployment of large numbers of outdoor U-NII-1 access points since 2014. This noise rise will increase further in the future as additional outdoor U-NII-1 access points are deployed in the United States, as the utilization of these access points increases, and as other interference sources become more widespread, such as wireless carrier systems utilizing LTE for supplemental downlink in the U-NII-1 band. The noise rise at 5170-5250 MHz has caused a decrease in Globalstar CDMA capacity and a decrease in satellite RF power capacity, both of which exceed ITU-R recommended limits. Both degradations will become more severe as more outdoor U-NII-1 access points are deployed.

9.1 Impact on Globalstar Operations Caused by Outdoor Wi-Fi Access Point Deployment

The introduction of interference in the Globalstar feeder uplink due to outdoor U-NII-1 access point operations destroys the balance between 1) the performance requirements and operational constraints of RF power transmitted to the user devices; 2) the RF satellite power available for user communications; 3) the uplink and overall RF signal-to-noise-plus-interference; 4) the geographic service availability; and 5) user capacity. Globalstar user capacity, geographic service availability, and call quality performance cannot be maintained with the addition of uncontrolled numbers of Wi-Fi access points and other emitters such as LTE-LAA in the U-NII-1 band.

The following is a summary analysis of the harm to Globalstar if outdoor deployment of Wi-Fi access points at 5170-5250 MHz and other devices in U-NII-1 continues:

1. *Noise rise on the Globalstar feeder uplink will increase for satellites operating over North America.*
   In the U.S., outdoor U-NII-1 access point operations were permitted by the FCC in 2014. Currently, Globalstar is measuring a noise rise of 2 ±0.5 dB over North America on six of the eight satellites being monitored, with a 1 ±0.5 dB on the other satellites, during the daylight periods.[67] The 2 dB noise rise first began to be observed in March, 2017, shortly after the measurements of a 1 dB rise. The 1 dB noise rise observed in 2017 is consistent with the interference generated by one million outdoor access points operating in compliance with FCC regulations and with a busy hour duty cycle of 10%, and is also consistent with the

[67] Noise rise values of 1 and 2 dB in 5096-5250 MHz are attributed to noise rise values of 1.8 and 3.3 dB, respectively, due to the presence of Wi-Fi access points in 5170-5250 MHz.

interference generated by 500 thousand outdoor access points with a 20% duty cycle. The deployment of 500 thousand to one million outdoor access points in the 5170-5250 MHz band is consistent with NCTA's statement that cable operators had deployed a total of 19.7 million access points in the U.S. as of June 2017 and its statement in October 2016 that 54% of all cable operators' deployed access points in the U.S. operate in the U-NII-1 band. With higher duty cycles, smaller numbers of outdoor access points can generate the observed noise rise. With industry-forecasted access point growth rates of 35-43% per year, Globalstar by 2022 will likely experience a feeder uplink noise rise between 4.7 dB and 5.8 dB in 5170-5250 MHz if the average access point duty cycle is 10%. The feeder uplink noise rise will likely be between 6.9 dB and 8.2 dB in 5170-5250 MHz if the average access point duty cycle is 20%. A noise rise of 8.2 dB would represent a nearly seven-fold increase in the noise floor, significantly exceeding the noise level for which the Globalstar system was designed.

2. *CDMA capacity and RF power capacity will decrease.*
   A noise rise in Globalstar's feeder uplink spectrum degrades the Globalstar satellite-to-handset downlink at 2.4 GHz, resulting in a reduction of Globalstar user capacity. In 2022, a 5.8 dB noise rise in 5170-5250 MHz caused by 6 million outdoor U-NII-1 access points with an average duty cycle of 10% would degrade Globalstar CDMA capacity in the geographic regions served by the affected spot beams by 19%, a significant busy period degradation. A 5.8 dB noise rise would also degrade Globalstar satellite RF power capacity (and user capacity) by 8% during busy periods, a significant degradation. In 2022, an 8.2 dB noise rise caused by 6 million outdoor U-NII-1 access points with an average duty cycle of 20% would degrade Globalstar CDMA capacity in the geographic regions served by the affected spot beams by 35%, a significant busy period degradation. An 8.2 dB noise rise would also degrade Globalstar satellite RF power capacity (and user capacity) by 15% during busy periods, a significant degradation.

3. *Quality of service will degrade.*
   Degradation of the Globalstar satellite-to-user handset downlink at 2.4 GHz will cause decreased geographic availability, increased dropped calls, and increased call attempt failures to Globalstar users.

9.2 Recommendation

Globalstar will suffer substantial degradation to its MSS traffic capacity and satellite power consumption if an unlimited deployment of outdoor Wi-Fi access points and other emitters such as LTE-LAA in the U-NII-1 band continues as allowed under current FCC regulations. It is recommended that the FCC take action to protect Globalstar's MSS operations and its customers from harmful aggregate interference from outdoor U-NII-1 access points.

Appendix A: Urbanized Areas and Expected Access Points

The following tables present a list of the U.S. urbanized areas according to their population area and geographic area in square miles. A column has been added to indicate the corresponding geographic area in square kilometers. The number of APs is then calculated from a ratio of 16 APs/km^2. This ratio uses the deployment of wireless access points in Mountain View, California in 2014 as an example of how an unlicensed wireless internet access service could be deployed in an urbanized area. (We note that in 2017, the Mountain View deployment featured 23 APs/km^2.) These tables also show the number of wireless access points for the top 41 urbanized areas, and the total number of wireless access points needed to cover the entire US urbanized area. A summary of these results is tabulated below.

Table A-1. Summary of Urban Density and Number of APs

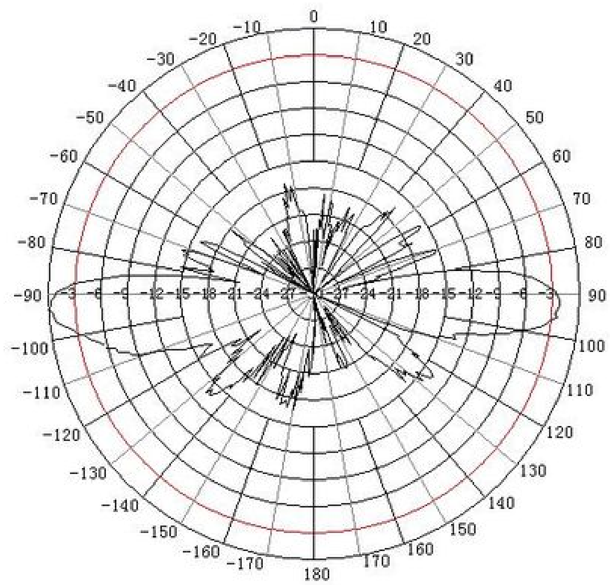
Continent	Urban Population	Urban Area	Number APs
North America	249 million	277 thousand sq-km	4.4 million

Table A-2. North American Urban Areas

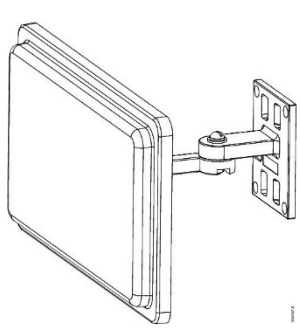
Rank	Urban Area	Population	Land Area Sq-mi	Land Area Sq-km	Number APs 16/sq-km
1	New York--New ark, NY--NJ--CT	18,351,295	3,450	8,970	143,520
2	Los Angeles--Long Beach--Anaheim, CA	12,150,996	1,736	4,514	72,218
3	Chicago, IL—IN	8,608,208	2,443	6,352	101,629
4	Miami, FL	5,502,379	1,239	3,221	51,542
5	Philadelphia, PA--NJ--DE--MD	5,441,567	1,981	5,151	82,410
6	Dallas--Fort Worth--Arlington, TX	5,121,892	1,779	4,625	74,006
7	Houston, TX	4,944,332	1,660	4,316	69,056
8	Washington, DC--VA—MD	4,586,770	1,322	3,437	54,995
9	Atlanta, GA	4,515,419	2,645	6,877	110,032
10	Boston, MA--NH—RI	4,181,019	1,873	4,870	77,917
11	Detroit, MI	3,734,090	1,337	3,476	55,619
12	Phoenix--Mesa, AZ	3,629,114	1,147	2,982	47,715
13	San Francisco--Oakland, CA	3,281,212	524	1,362	21,798
14	Seattle, WA	3,059,393	1,010	2,626	42,016
15	San Diego, CA	2,956,746	732	1,903	30,451
16	Minneapolis--St. Paul, MN--WI	2,650,890	1,022	2,657	42,515
17	Tampa--St. Petersburg, FL	2,441,770	957	2,488	39,811
18	Denver--Aurora, CO	2,374,203	668	1,737	27,789
19	Baltimore, MD	2,203,663	717	1,864	29,827
20	St. Louis, MO—IL	2,150,706	924	2,402	38,438
21	Riverside--San Bernardino, CA	1,932,666	545	1,417	22,672
22	Las Vegas--Henderson, NV	1,886,011	417	1,084	17,347
23	Portland, OR—WA	1,849,898	524	1,362	21,798
24	Cleveland, OH	1,780,673	772	2,007	32,115
25	San Antonio, TX	1,758,210	597	1,552	24,835
26	Pittsburgh, PA	1,733,853	905	2,353	37,648
27	Sacramento, CA	1,723,634	471	1,225	19,594
28	San Jose, CA	1,664,496	286	744	11,898
29	Cincinnati, OH--KY—IN	1,624,827	788	2,049	32,781
30	Kansas City, MO—KS	1,519,417	678	1,763	28,205
31	Orlando, FL	1,510,516	598	1,555	24,877
32	Indianapolis, IN	1,487,483	706	1,836	29,370
33	Virginia Beach, VA	1,439,666	515	1,339	21,424
34	Milwaukee, WI	1,376,476	546	1,420	22,714
35	Columbus, OH	1,368,035	510	1,326	21,216
36	Austin, TX	1,362,416	523	1,360	21,757
37	Charlotte, NC—SC	1,249,442	741	1,927	30,826
38	Providence, RI—MA	1,190,956	545	1,417	22,672
39	Jacksonville, FL	1,065,219	530	1,378	22,048
40	Memphis, TN--MS—AR	1,060,061	497	1,292	20,675
41	Salt Lake City--West Valley City, UT	1,021,243	278	723	11,565
	Total	133,490,862	41,139	106,961	1,711,382
	Other Urban Areas	115,762,409	65,247	169,642	2,714,275
	Total Urban	249,253,271	106,386	276,604	4,425,658

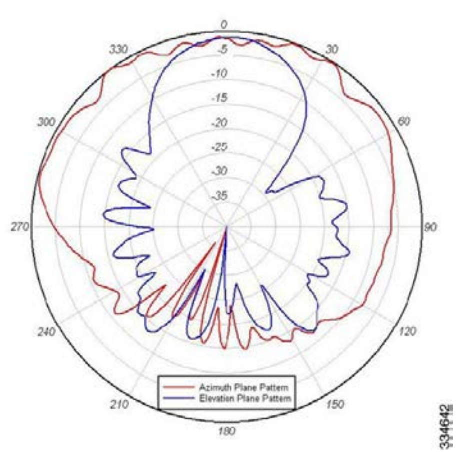
Appendix B: Unlicensed Access Point Antenna Parameters

Antenna patterns for wireless LAN access points deployed outdoors can vary depending on antenna gain and directionality. One typical omnidirectional antenna for outdoor mounts for wireless LAN applications is illustrated below. The mast is 0.93 m long. The vertical antenna pattern at 5 GHz is also shown. The gain is 6 dBi at 5200 MHz with 22° of vertical beam width. The side lobes of the pattern are attenuated about 15 dB.

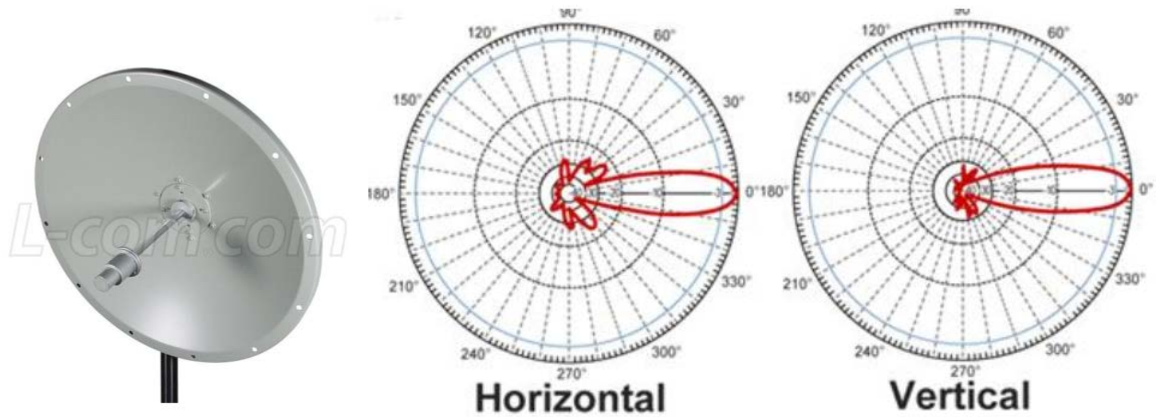


A different antenna design is represented by a flat panel antenna intended for directional outdoor mounts, such as on a wall. This panel is about 31 cm by 18 cm. This antenna has approximately 8 dBi of gain at 5200 MHz and about 15 dB of side lobe attenuation, with a vertical beam width of approximately 40°.





A typical example of a directional parabolic dish antenna is shown next. The dish is 87 cm in diameter. The horizontal and vertical radiation patterns at 5000 MHz are nearly symmetrical with a gain of 23 dBi, beam width of 9°, and approximately 25 dB of side lobe attenuation.



Interference Power Flux Density Link Budgets

The interference power flux density for the different AP antennas is calculated in the link budget table below according to the formula for Φ in equation E-1a. The calculations are for elevation angles that obtain the average flux density over all APs in the satellite viewing area as calculated in equation E-5b. Table B-1 is for information only, to show how representative elevation angles can obtain flux densities comparable to the calculations in Table 2. The actual calculations in Table 2 were done with equation E-5b.

Table B-1. Interference Power Flux Density for Different Antennas

	Omni stick		Directional wall panel		Directional gain dish	
P Watts	1		1		1	
Bandwidth MHz	80		80		80	
P W/MHz	0.0125		0.0125		0.0125	
P dBW/MHz		-19.0		-19.0		-19.0
ε degrees	15.53		35.00		7.78	
θ degrees	22.43		12.90		28.04	
$G_{AP}(\varepsilon,0)$ dBi	-5.6		-2.2		18.9	
Azimuth average dB	0.0		-3.0		-15.6	
$G_{AP}(\varepsilon)$ dBi		-5.6		-5.2		3.3
D km	3082		2122		3694	
$-20 \log_{10}(4 \pi D^2)$ dB		-140.8		-137.5		-142.3
Φ dBW/MHz-m^2		-165.4		-161.7		-158.1

Example Access Point Deployment

Figure 26 is an example of outdoor wireless LAN deployment on the Illinois Institute of Technology campus in Chicago, Illinois.

Figure 26: Outdoor Access Point Deployment, September 2017

The access point antennas are located approximately 6 meters above sidewalk level. While shadowed to the east, the access point has a nearly clear line of sight in the direction of the photo over an azimuthal angle of nearly 135 degrees (directly south to northwest.)

Example Mountain View California Deployment

On February 19, 2014 the City of Mountain View and Google announced a new connectivity plan for residents. Google was providing free, public outdoor Wi-Fi in Mountain View along the downtown corridor, primarily Castro Street.[68] In 2014 RAA calculated an AP density of 16 APs/km^2 from this deployment. Since 2014 additional deployments have occurred in Mountain View, as shown in a map in Figure 27. This shows deployment of more than 1100 hotspots within a circle of 3.9 km for a density of 23 APs/km^2. This demonstrates a rapid growth of Wi-Fi deployment without any restraint.

[68] *See* http://www.mountainview.gov/about/learn/freewifi.asp.

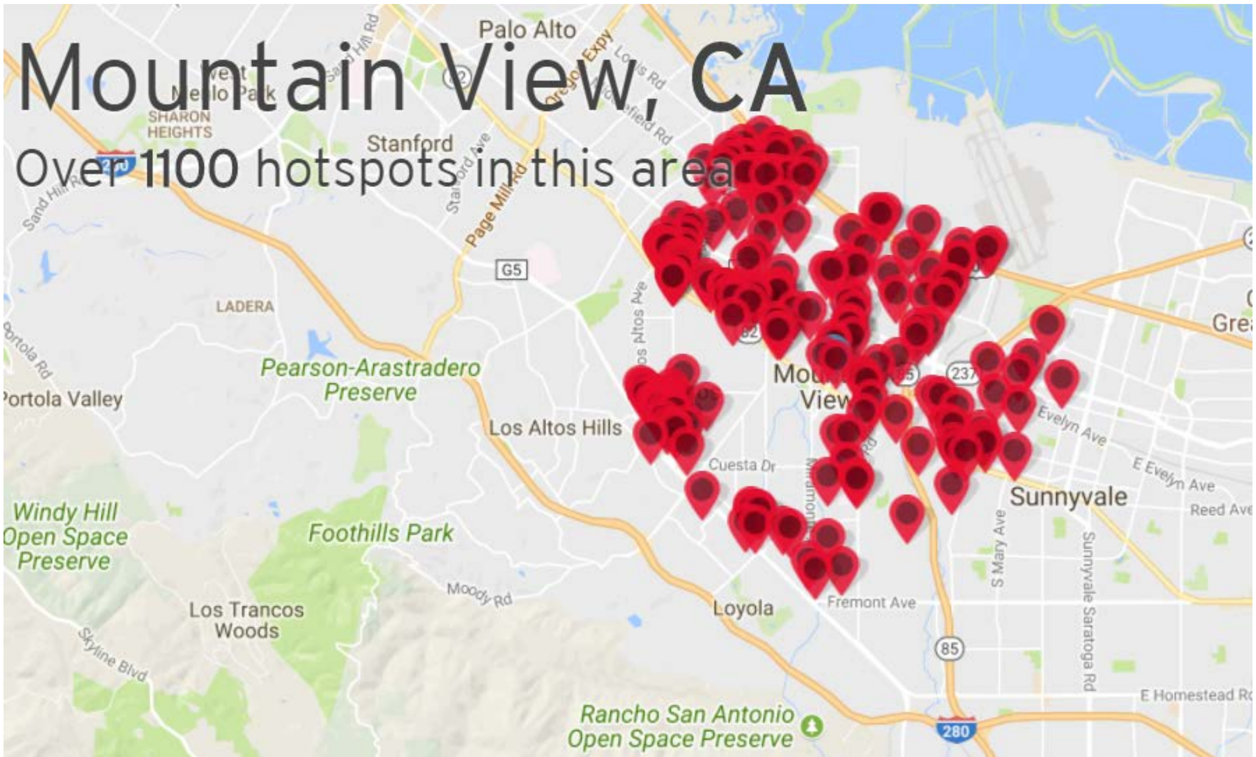


Figure 27: Hotspots in Mountain View in 2017

Example 2018 Outdoor LTE Deployment in Chicago

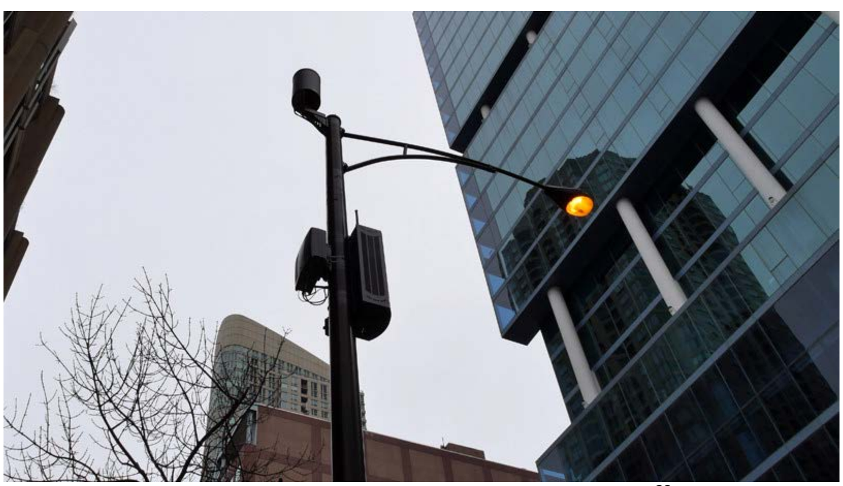


Figure 28: LAA Small Cell Site in Chicago[69]

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[69] "Exclusive: AT&T LTE Hits 537 Mbps in Chicago," *PC Mag*, March 29, 2018, accessed at https://www.pcmag.com/news/360113/exclusive-at-t-lte-hits-537mbps-in-chicago.

Appendix C: Impact of Access Point Interference on CDMA Downlink Capacity

C.1 Interference Characterization in the Globalstar CDMA Downlink

In the Globalstar CDMA downlink channels, multiple individual users share the same CDMA channel within a satellite beam using orthogonal codes. Adjacent satellite downlink beams re-use identical CDMA channels (frequencies) from beam to beam (single frequency re-use). The downlink capacity is therefore limited primarily by three factors: 1) the power available in the satellite for distribution to the individual CDMA users and channels; 2) the co-channel interference in a beam caused by co-channel CDMA users in adjacent beams; and 3) adjacent–channel interference caused by CDMA users in the same beam.

Co-channel and adjacent-channel interference scenarios in the Globalstar CDMA downlinks are illustrated in Figure 29. The roughly trapezoidal-shaped and circular regions are the satellite-to-mobile user device downlink beams for individual satellites in the Globalstar constellation. Adjacent channel interference occurs primarily within a downlink beam, while co-channel interference occurs between adjacent beams and adjacent satellites, as shown in the Figure.

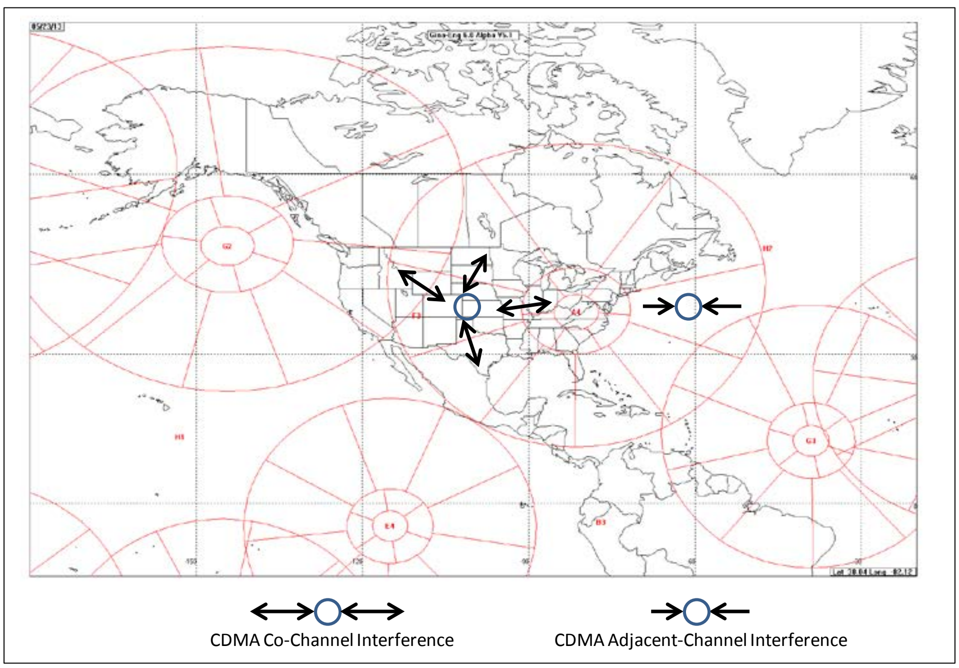


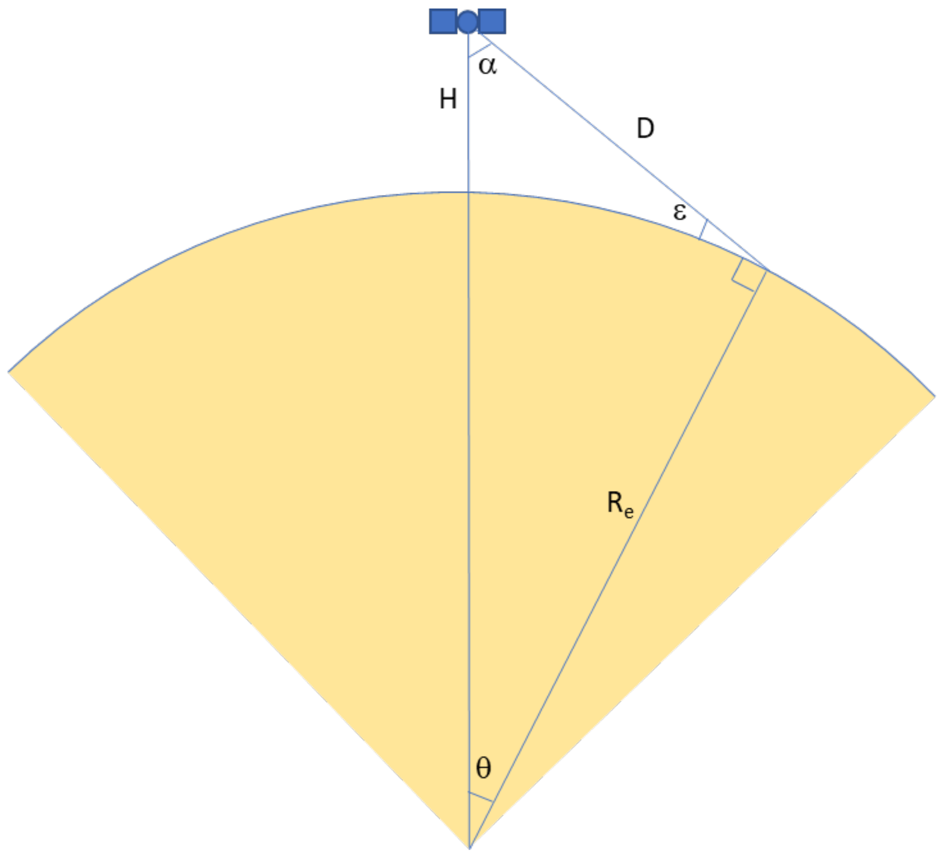
Figure 29: Illustration of Inherent CDMA Downlink Interference

Since the power available at the satellite is fixed, degradation in the overall Globalstar downlink CDMA channels cannot be remedied without impacting capacity or communication link geographic coverage reliability. In order to estimate the impact of overall downlink channel degradation on GLOBALSTAR performance, we assume that the transmit power available at the satellite for the downlink is fixed. Keeping geographic coverage reliability (geographic availability of coverage to the end user) constant, any overall downlink increase in interference due to external sources (for example, unlicensed access points in the ground station to satellite feeder link) must then be compensated for by a reduction in the inherent CDMA co-channel and adjacent channel interference on the downlink. Since the inherent CDMA co-channel and adjacent-channel interference is directly related to the number of co-channel and adjacent channel users, the capacity reduction of the Globalstar CDMA downlink can be estimated by calculating the reduction in users needed to maintain acceptable $Eb/(No+Io)_{ovr}$ on the downlink, where Io is the resultant total interference inherent to CDMA, plus the interference due to external sources.

Appendix D: Geometry of Satellite to Ground Path

This appendix is a brief description of the geometric and trigonometric calculations to determine path distances and angles between a satellite and a ground location. This appendix also includes calculations of shadowing effects from buildings and local terrain. The starting parameters are:

R_e = radius of the earth = 6371 km



H = satellite altitude above the earth = 1414 km

The triangle with vertices at the center of the earth, the satellite, and the ground location, has the following angles:

α = angle at the satellite
ε = elevation angle at a ground location above the horizon to the satellite
θ = central earth angle (geocentric angle)

The triangle has 2 sides that are known (R_e and R_e+H), so any angle is sufficient to allow the calculation of the remaining parts of the triangle. The elevation angle ε is most easily measured at a ground location. The geocentric angle θ is a convenient variable for calculations over the entire coverage area of the satellite. The following equations will permit the solution of the triangle parts given either angle ε or θ. Equation D-1 is derived from the sum of angles (in radians) in a triangle, less the right angle at the ground location:

$$\pi/2 = \alpha + \varepsilon + \theta \qquad \text{Eq. D-1}$$

The Law of Sines is given in equation D-2.

$$\frac{\sin(\frac{\pi}{2}+\varepsilon)}{R_e+H} = \frac{\sin(\alpha)}{R_e} = \frac{\sin(\theta)}{D} \qquad \text{Eq. D-2}$$

Equation D-1 can be used to substitute for α in equation D-2 to obtain an equation relating ε and θ. We can use a trigonometric identity to convert $\sin(\pi/2 \pm x)$ to $\cos(x)$. The result is equation D-3. This permits the calculation of θ from ε, as given in equation D-4.

A useful limit is obtained with ε=0. From equation D-4, $\theta_m(\varepsilon=0) = \cos^{-1}(R_e/(R_e+H)) = 0.6122$ rads = 35.1°. The arc length for the angle θ_m is $\theta_m R_e$ = 3901 km. The distance to the satellite, D_m=4474 km.

If both θ and ε are known then D can also be calculated by equation D-5.

$$\frac{\cos(\varepsilon)}{R_e+H} = \frac{\cos(\theta+\varepsilon)}{R_e} = \frac{\sin(\theta)}{D} \qquad \text{Eq. D-3}$$

$$\theta = \cos^{-1}\left(\frac{R_e\cos(\varepsilon)}{R_e+H}\right) - \varepsilon \qquad \theta_m = \theta(\varepsilon=0) = 0.6122 \text{ rads} \qquad \text{Eq. D-4}$$

$$D = (R_e + H)\frac{\sin(\theta)}{\cos(\varepsilon)} \qquad \text{Eq. D-5}$$

Another way to calculate D is from the Law of Cosines using the geocentric angle θ. With a little algebra, the result is equation D-6.

$$D = (R_e + H)\sqrt{1 + \left(\frac{R_e}{R_e+H}\right)^2 - 2\frac{R_e}{R_e+H}\cos(\theta)} \qquad \text{Eq. D-6}$$

The relations in equation D-3 can also be used to calculate the elevation angle ε from the geocentric angle θ and the path distance D. In this case, D can be calculated using equation D-6, and then equation D-7 can be used to calculate ε.

$$\varepsilon = \cos^{-1}\left(\frac{R_e+H}{D}\sin(\theta)\right) \qquad \text{Eq. D-7}$$

The area of the earth surface under the satellite and within geocentric angle θ is given by equation D-8. This is the area of a spherical cap with a half-angle θ.

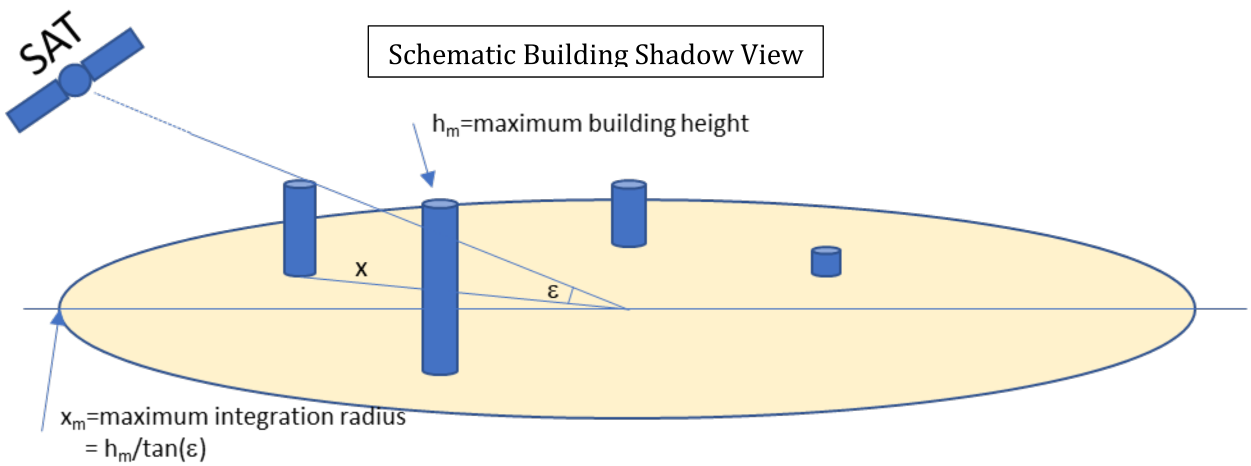
$$A_o = 2\pi R_e^2(1-\cos(\theta)) \qquad \text{Eq. D-8}$$

The global viewing area under the satellite is $A_o(\theta=\theta_m) = 46.3 \times 10^6$ km^2, or about 9% of the total earth surface.

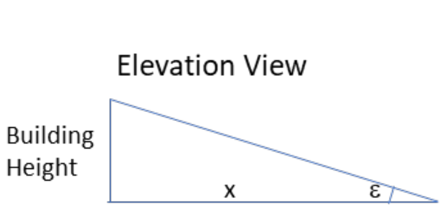
Building Shadows

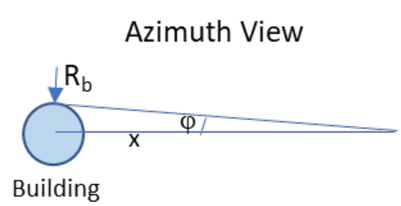
At low elevation angles the line of sight path from the ground to the satellite is sometimes interrupted by a building. This is a building shadow. The probability of a building shadow can be averaged over the area beneath the satellite to attenuate the total interference power from the APs on the ground. This attenuation is a direct function of the number of buildings (N_b) in the line of sight path. The calculation of N_b will use the following parameters.

D_b = density of buildings per hectare (1 hectare = 10^4 m^2)
R_b = average radius of a building in meters
ρ_b = building density ratio = $\pi R_b^2 D_b / 10^4$; should be in range 0..1
P_h = PDF (probability density function) of building heights
C_h = CDF (cumulative density function) of building heights = $\int_0^h P_h(x)dx$
N_b = average number of buildings to cast a shadow at the elevation angle ε



To estimate N_b as a function of elevation angle ε, we compute the number of buildings high enough to cast a shadow per unit of area on the azimuth of the line of sight. The necessary height to cast a shadow at a distance of x along the ground, and elevation angle ε is h(ε)=x tan(ε). The azimuth angle for the shadow is ±φ where $\varphi=\sin^{-1}(R_b/x)$. These relations are illustrated in the elevation and azimuth views in the figures below.





The probability that a building will be high enough to cast such a shadow is the complement of C_h, or 1-C_h = 1 – C_h(x tan(ε)). So the incremental probability that such a building is at distance x and the correct azimuth to cast a shadow is then the product of these expressions with the density of buildings:

ΔProb[building shadow] = 2 $D_b \sin^{-1}(R_b/x)$ [1 – $C_h(x \tan(\varepsilon))$] x dx.

This can then be integrated in equation D-9 with the variable x over the range R_b to infinity to estimate the number of buildings to cast a shadow.

$$N_b(\varepsilon) = \int_{R_b}^{\infty} 2D_b \sin^{-1}\left(\frac{R_b}{x}\right)[1 - C_h(x\tan(\varepsilon))]\, x\, dx \qquad \text{Eq. D-9}$$

This integral is easy to evaluate numerically for some combination of input parameters. The complementary CDF function 1-C_h goes to zero for sufficiently large building heights, since buildings have a practical upper limit on height. This means that the infinite upper limit on the integral is actually finite in practice, as determined by the limits on height. The upper limit on the integral is x_m=h_m cot(ε) for the maximum building height h_m. This limit is noted in the schematic building shadow view.

The probability that the line of sight from an AP on the ground to a satellite is shadowed is derived from N_b by simply observing that when N_b>1, the probability of a shadow is unity. In such a case, the attenuation is estimated from an attenuation factor (shdb), multiplied by N_b:

Attenuation in dB = shdb × N_b ; for $N_b \geq 1$

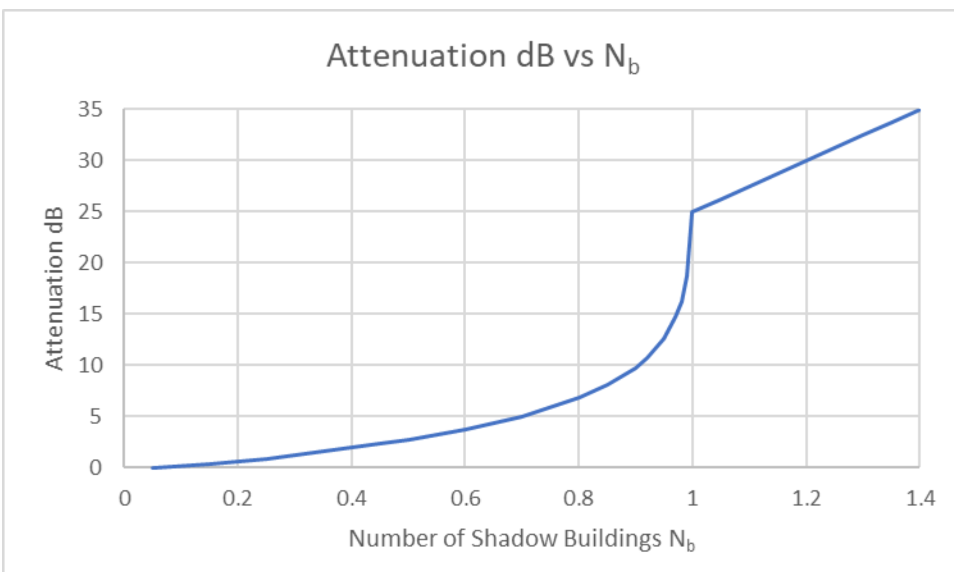
When N_b<1, the probability of a shadow is simply N_b. This is easily expressed with the min() function:

Prob[shadow] = min(1, $N_b(\varepsilon)$) Eq. D-10

The attenuation from buildings for N_b<1 is summed from the two cases, in-shadow and not-in-shadow. The attenuation for not-in-shadow is 0 dB. The attenuation in-shadow is shdb×N_b.

Attenuation in dB = 10 $\log_{10}$(1 – N_b + $N_b\, 10^{0.1\,\text{shdb}\,N_b}$) ; for N_b<1

In combination with the case for N_b>1 the overall power attenuation factor increases linearly for 0<N_b<1 and exponentially for N_b>1. This is shown in the graph for shdb = 25 dB.



The distribution PDF of building heights, P_h, is constructed from a combined discrete and continuous distribution, $p_h(h)$ and z(h) respectively. The discrete distribution models building heights as discrete stories or floors, spaced some distance apart vertically, such as 3 meters. One possible distribution of p_h would be [8/15, 4/15, 2/15, 1/15] for probabilities at discrete heights of [3, 6, 9, 12] meters, respectively. This models the population of buildings as a distribution from 1 to 4 floors.

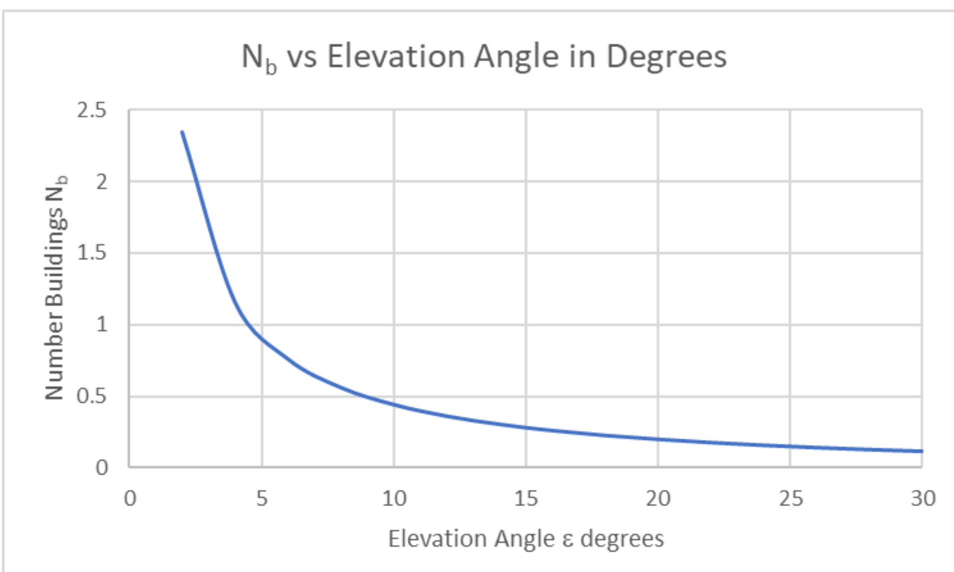
The continuous distribution for height, z(h), accounts for local variations in terrain elevations. This uses some convenient distribution, such as a normal distribution, with a zero mean and a variance of σ^2.

$$z(h) = \frac{1}{\sqrt{2\pi}\sigma} e^{-0.5\,(h/\sigma)^2} \qquad \text{Eq. D-11}$$

The overall building height is then the sum of the discrete height distribution $p_h(h)$ with the local terrain elevation z(h).

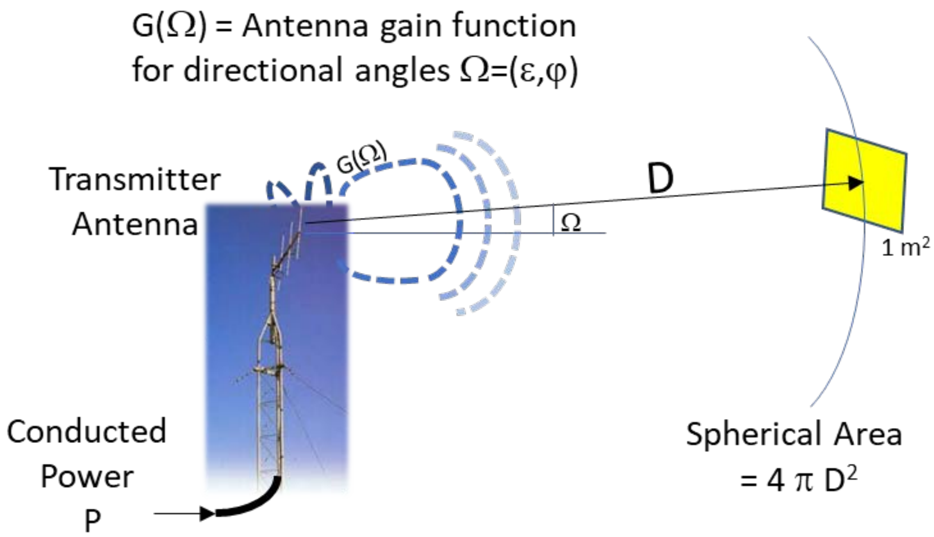
The final effect in considering building shadows is the height of the ground location for mounting the antenna. This height is considered to be above the ground, so this is decremented from the overall building height in the evaluation of the integral for N_b.

An example of a calculation of $N_b(\varepsilon)$ for elevation angles from 0 to 30° is given in the figure. This calculation is for a discrete distribution of building heights from 1 story to 4 stories, 3 meters per story, with a building density ratio of ρ_b=8% of the land area occupied by buildings, and terrain variation σ=3m and 3m height for the AP antenna at the ground location. This shows that buildings will strongly attenuate paths to the satellite below 4° of elevation, while having only slight effects for elevations higher than 20°.



Appendix E: Power Flux Density of Interference

The power flux density from interference can be calculated at the satellite from a co-channel interfering transmitter on the ground. The interfering transmitter is modeled with representative antennas that direct the signal along the ground for terrestrial purposes as described in Appendix B, while giving some attenuation at elevation angles above the ground. The distance to a satellite depends on the geometric parameters for the satellite-to-ground path as described in Appendix D.



The transmitted power flux density, Φ, is given by equations E-1a and E-1b for a conducted transmit power output P, directional gain $G_{AP}(\varepsilon,\varphi)$, and a factor for power dissipation over a sphere of radius D. If P is expressed as a power spectral density in W/MHz, and D is in meters, then Φ is in units of W/MHz-m^2. This is converted to dBW/MHz-m^2 for convenient units of W/MHz and kilometers.

$$\Phi = \frac{P\, G_{AP}(\varepsilon,\varphi)}{4\pi\, D^2} \qquad \text{Eq. E-1a}$$

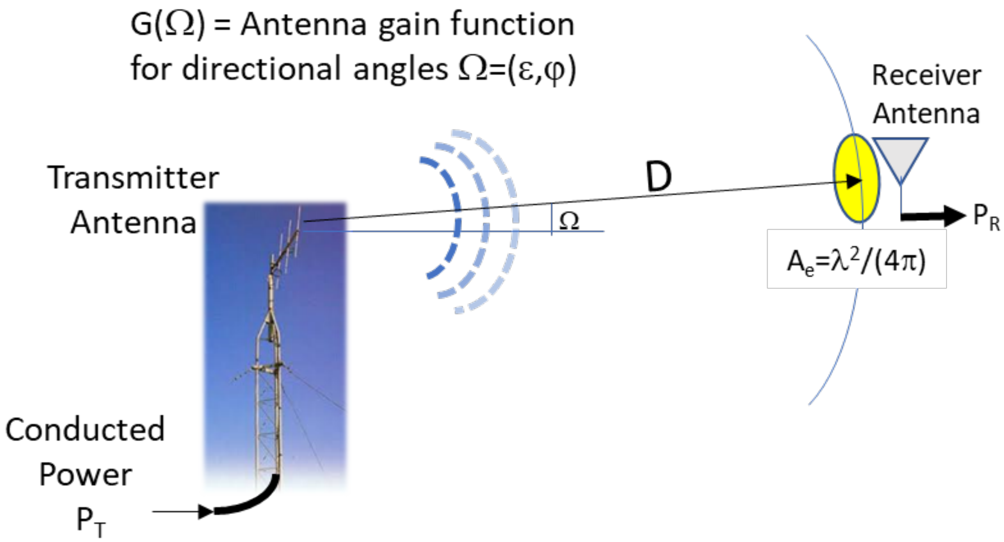
$$\Phi \text{ dBW/MHz-m}^2 = -70.992 + 10 \log_{10}(P \text{ W/MHz}) + G_{AP}(\varepsilon,\varphi) \text{ dB} - 20 \log_{10}(D \text{ km}) \qquad \text{Eq. E-1b}$$

For example, for a single transmitter with conducted power output of 1.0 W in a 20 MHz bandwidth, a directional antenna gain of 23 dBi, at a distance of D_m= 4474 km, the power flux density at the satellite would be Φ = -134 dBW/MHz-m^2. If there were 10 such transmitters placed on the ground somewhere on a circle of radius 3901 km under the satellite, then the total power flux density would be -124 dBW/MHz-m^2 to reach the recommended limit of ITU-R S.1426 (2000), and also the recommended limit in ITU-R S.1432.

The propagation path to the satellite creates a parameter known as the path loss, L_p, customarily calculated according to equations E-2a and E-2b, for a distance D from the ground location to the satellite, and a wavelength $\lambda=c/f_c$, for the given carrier frequency f_c. This is converted to dB for convenient units of kilometers and GHz, with c=299,792 km/s.

$$L_p = \left(4\pi \frac{D}{\lambda}\right)^2 = (4\pi f_c D/c)^2 \qquad \text{Eq. E-2a}$$

L_p dB = 92.448 + 20 $\log_{10}$(f_c GHz) + 20 $\log_{10}$(D km) Eq. E-2b



The Friis transmission equation connects the conducted transmit power into a transmitter antenna, P_T, with gain G_T, to the conducted receiver power, P_R, out of a receiver antenna with gain G_R and the path loss L_p as in equation E-3a. This can be adjusted to use the power flux density at the receiver, Φ_R in equation E-3b. This leads to equation E-3c to connect the flux density at the receiver with antenna gain G_R. To connect system noise to power flux density we equate the receiver power to k T B for Boltzmann's constant, absolute temperature, and bandwidth, respectively. This leads to the system noise power flux density at the receiver in equation E-3d.

$P_R = P_T\, G_T\, G_R / L_p = P_T\, G_T\, G_R\, (\lambda / (4\, \pi\, D))^2$ Eq. E-3a

$\Phi_R = P_T\, G_T / (4\, \pi\, D^2)$ Eq. E-3b

$P_R = \Phi_R\, G_R\, \lambda^2/(4\pi) = k\, T\, B$ Eq. E-3c

$\Phi_{noise} = 4\, \pi\, k\, T\, B / (G_R\, \lambda^2)$ Eq. E-3d

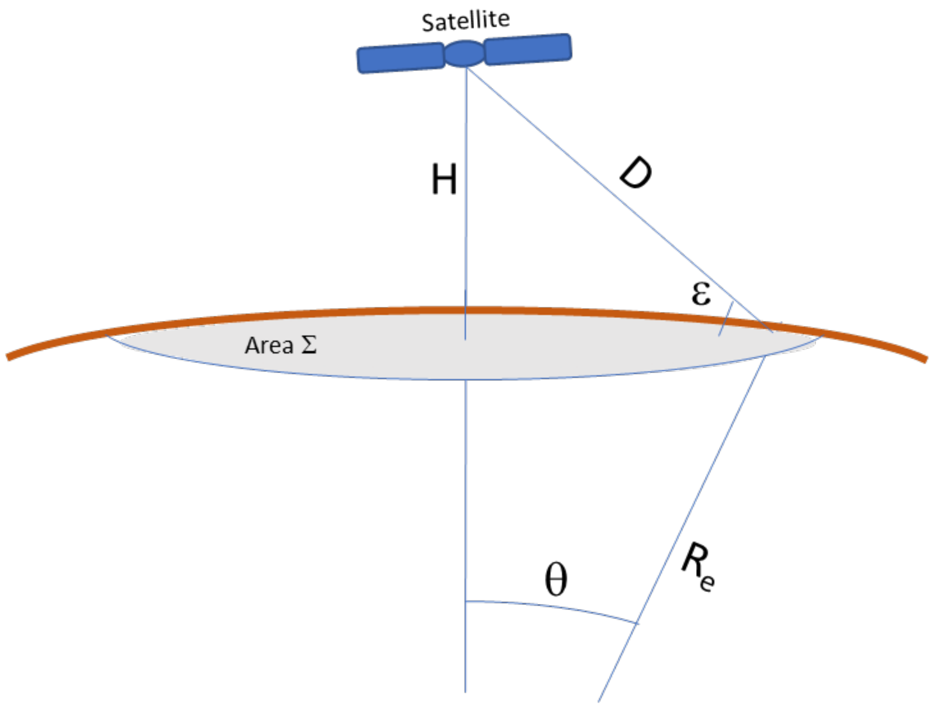
For k=1.3806 x 10^{-23} J/K, T=298°K, B=1.0 MHz, G_R=2.36 (for 4 dBi gain), and λ=5.765 cm (f_c=5.2 GHz), we obtain the system noise power flux density in equation E-3e. This is also used in equation 1.

Φ_{noise} = -111.8 dBW/MHz-m^2 Eq. E-3e

The noise rise at the satellite receiver can be calculated by comparing the Φ in equation E-1 with the Φ_{noise} given in equation E-3e.

Average Interference Power Flux Density

Terrestrial Wi-Fi access point systems include Access Point (AP) transmitters distributed on the ground. A simple calculation of average interference power flux density from APs can start with a uniform distribution on the ground. Each AP uses a transmit antenna with some antenna gain pattern G relative to an isotropic source, usually given in dBi as a function of elevation angle (ε) and azimuth angle. Representative gain patterns are shown in Appendix B.



The calculation of average power flux density at the satellite for an AP antenna anywhere on the ground in area Σ, with conducted power P, antenna gain G(Ω), building shadow function *Shadow*(ε), and satellite distance D(θ), can be found by integrating the Φ function of equation E-1, multiplied by a *Shadow* function, over the area Σ and then dividing by the area Σ (see equation D-8 for A_o). This is shown in equation E-4.

$$\Phi_{avg} = \frac{\iint_{\Sigma} \Phi(\Omega) dA}{A_o(\theta_m)} = \frac{\iint_{\Sigma} \frac{P\, G(\Omega)\, Shadow(\varepsilon)}{4\, \pi\, D(\theta)^2} dA}{2\pi R_e^2 (1-\cos(\theta_m))} \qquad \text{Eq. E-4}$$

If we expand the area integral into separate integrals over geocentric angle θ and azimuth angle φ we obtain equation E-5a. We average over the azimuth angle φ to reach the equation with a single integral over geocentric angle θ in equation E-5b. The factors of 2 π R_e^2 cancel for some simplification.

$$\Phi_{avg} = \frac{1}{A_o} \int_0^{\theta_m} \int_0^{2\pi} \Phi(\Omega)\, R_e^2 \sin(\theta)\, d\varphi\, d\theta \qquad \text{Eq. E-5a}$$

$$\Phi_{avg} = \frac{2\pi R_e^2}{A_o} \int_0^{\theta_m} \Phi(\varepsilon)\sin(\theta)\, d\theta = \frac{\int_0^{\theta_m} \frac{P\, G(\varepsilon)\, Shadow(\varepsilon)}{4\pi D(\theta)^2} \sin(\theta) d\theta}{1-\cos(\theta_m)} \quad \text{Eq. E-5b}$$

The average over the azimuth angles includes an average for the antenna gain G(Ω) over the azimuth angle to result in a simplified average gain as a function of the elevation angle G(ε). For omni directional antennas such as the vertical stick antenna in Appendix B, this average is already provided in the gain function.

Appendix D shows the calculation of the elevation angle, ε, as a function of the geocentric angle θ for all ground locations within view of the satellite. For a satellite in orbit at 1414 km, the radius on the ground of the viewing area under the satellite is 3901 km. The elevation angle above the local ground horizon can decrease to 0° at the edge of the satellite view of the ground, *i.e.*, anywhere on a circle of radius 3901 km centered under the satellite. The limit for the geocentric angle for the viewing area is θ_m=35.1°, as is shown in Appendix D equation D-4.

The *Shadow*(ε) function accounts for building shadows at low elevation angles. This is discussed in Appendix D. For some AP applications, such as point-to-point links, the building shadow function will not be a factor since point-to-point links are designed to propagate over paths free of any obstacles.

The integral for Φ_{avg} in equation E-5b is easily computed numerically by integration methods such as Simpson's Rule, Romberg integration, or Gaussian quadrature. For non-trivial *Shadow* functions, the evaluation of *Shadow*(ε) requires another numerical integration in equation D-9 that is also easily calculated. The result for Φ_{avg} is the average interference power flux density at the satellite from any terrestrial Wi-Fi access point transmitter randomly distributed within the viewing area of the satellite. This can then be multiplied by the total number of Wi-Fi access point transmitters to reach a total average interference power flux density and a resulting noise rise at the satellite.

North American Continental Land Mass Considerations

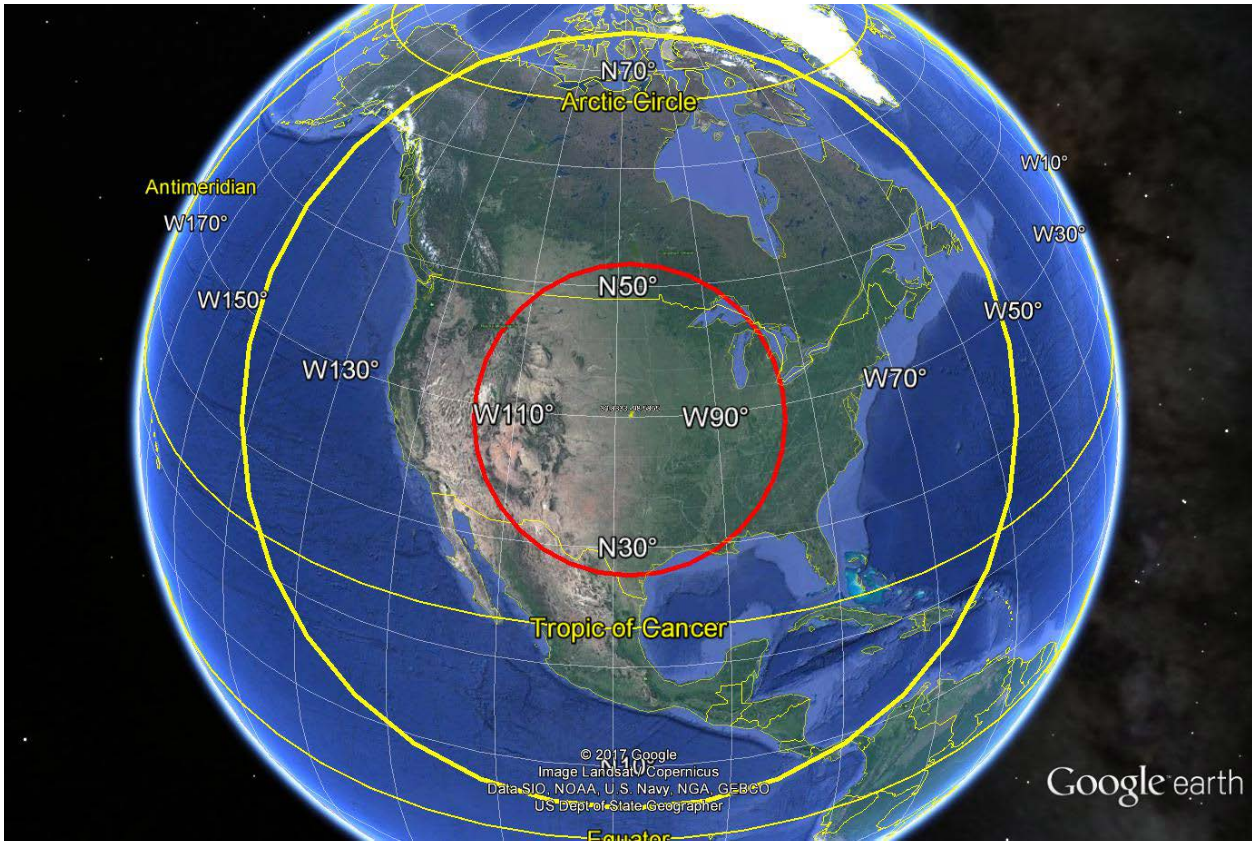
The primary abstraction for the calculation of interference power flux density at the satellite is that the interfering Wi-Fi access point transmitters are uniformly distributed over the land surface within the viewing area of the satellite. As calculated in Appendix D equation D-8, that area is very large: about 9% of the total earth surface. This part of the Appendix will compare that area with some continental areas and determine the impact on the abstract calculation method.

For North America, a convenient and perhaps arbitrary central point on the ground is determined as a target for calculation. For North America the chosen central point was Lebanon in Smith county, Kansas at latitude, longitude of 39.8333°N, 98.5855°W. Then the satellite orbits are plotted for a day to determine the closest satellite to the ground center point for each instant in time. The satellite orbits include the effects of the earth rotation so that every satellite in every orbital plane is swept past the ground center point. Statistics are then tracked for the ground distance between the ground center point and the nearest satellite at every instant in time. As might be expected, the nearest satellite could be several degrees away from the ground center point.

Ground distances are measured in this process along great circle arcs, and they are given as angles (degrees are the convenient unit). A degree of latitude is about 111 km on the earth's surface. The reader should note that at higher latitudes, such as in Canada, a degree of longitude is quite a bit less distance on the ground than a degree of latitude. At the pole, of course, a degree of longitude diminishes to 0 km.

North America is shown as a projection from Google Earth at an altitude of 11,000 km, centered at the chosen ground center. Then a circle of radius 35.1° or 3901 km is drawn in yellow to represent the viewing area of a hypothetical satellite. Another smaller red circle is drawn to represent the region of possible satellite locations that are nearest to the ground center. The radius of the red circle is calculated from satellite orbital positions over a 24-hour interval.

North American Continent



For North America, the satellite viewing area (yellow circle) extends beyond the continent shore line into both the Atlantic and Pacific oceans. The red circle shows possible satellite locations near the center of the continent. Any satellite within the red circle will receive interference from either continental shore or any urban area in North America (excluding Alaska). From the satellite view point, each interference transmitter is averaged over an area given by the red circle. In essence, the continental land area is convolved with a circular region equivalent to the red circle to approximate the total view area given by the yellow circle. This is represented by an average over the yellow region.

Appendix F. Best Wireless Routers of 2018[70]

Product	Lowest Price	Wireless Specification	5 GHz U-NII-1 Capable
D-Link AC1200 Wi-Fi Router (DIR-842)	$59.93	802.11ac	Yes
Linksys EA6350 AC1200+ Dual-Band Smart Wi-Fi...	$79.97	802.11ac	Yes
TP-Link Archer C7 AC1750 Wireless Dual Band G...	$89.96	802.11ac	Yes
Trendnet AC2600 StreamBoost MU-MIMO WiFi Router	$109.97	802.11ac	Yes
Synology Router RT2600ac	$194.99	802.11ac	Yes
Asus RT-AC86U AC2900 Router	$233.00	802.11ac	Yes
Linksys WRT32X Wi-Fi Gaming Router	$248.00	802.11ac	Yes
TP-Link Talon AD7200 Multi-Band Wi-Fi Router	$295.99	802.11ac, 802.11ad	Yes
D-Link AC5300 Ultra Wi-Fi Router (DIR-895L/R)	$322.69	802.11ac	Yes
Netgear Nighthawk X10 AD7200 Smart WiFi Route...	$412.99	802.11ac, 802.11ad	Yes

[70] Excerpted from *Best Wireless Routers of 2018*, PCMAG, Feb. 13, 2018 accessed at https://www.pcmag.com/article2/0,2817,2398080,00.asp.

Appendix G. Chicago Area 5 GHz Drive Test

RF measurements were recorded using a portable spectrum analyzer connected to an omni-directional 10 dBi gain antenna mounted on top of a van. RF power spectral density (PSD) scans were continuously recorded while the vehicle was driving in a northwest suburb of Chicago, over a period of 45 minutes at normal driving speeds. The red plot in Figure 30 below illustrates the output of the spectrum analyzer displayed in "peak hold" mode, that is, the peaks of the RF power encountered during the drive test were recorded. The plot clearly shows that there were no signals observed below 5170 MHz. However, significant power was observed in the frequency band 5170-5250 MHz where Wi-Fi IEEE channels are located, indicating the presence of RF transmitters in this region. Figure 31 shows the drive test route.

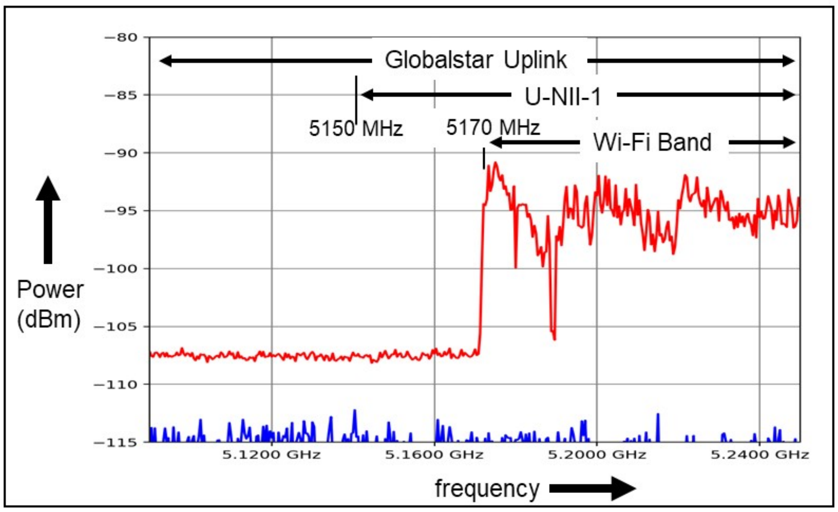


Figure 30: Spectrum Analyzer Plot 5 -5.25 GHz

Figure 31: Drive Test Route, Schaumburg, IL

Appendix H: Company Profile

Profile: Roberson and Associates, LLC

Roberson and Associates, LLC, is a technology and management consulting company with government and commercial customers that provides services in the areas of RF spectrum management, RF measurements and analysis, and technology management. The organization was founded in 2008 and is composed of a select group of individuals with corporate and academic backgrounds from Motorola, Bell Labs, IBM, IITRI (now Alion), independent consulting firms, and the Illinois Institute of Technology. Together the organization has over 400 years of the high technology management and technical leadership experience with a strong telecommunications focus.

Profiles: Roberson and Associates, LLC, Staff

Dennis A. Roberson, President and CEO, Roberson and Associates

Mr. Roberson is the Founder, President and CEO of Roberson and Associates, LLC. In parallel with this role he serves as Vice Provost for Research and Research Professor in Computer Science at Illinois Institute of Technology where he has responsibility for IIT's corporate relationships including IIT's Career Management Center, Office of Compliance and Proposal Development, Office of Sponsored Research and Programs, and Technology Transfer efforts. He also supports the development and implementation of IIT's Strategic Plan, the development of new research centers, and the successful initiation and growth of IIT related technology-based business ventures. He is an active researcher in the wireless networking arena and is a co- founder of IIT's Wireless Network and Communications Research Center (WiNCom). His specific research focus areas include dynamic spectrum access networks, spectrum occupancy measurement and spectrum management, and wireless interference and its mitigation and of which are important to the Roberson and Associates mission. He currently serves on the governing and / or advisory boards of several technology-based companies. Prior to IIT, he was EVP and CTO at Motorola and he had an extensive corporate career including major business and technology responsibilities at IBM, DEC (now part of HP), AT&T, and NCR. He is and has been involved with a wide variety of Technology, Cultural, Educational and Youth organizations currently including the Federal Communications Commission Technical Advisory Council and Open Internet Advisory Committee, the Commerce Spectrum Advisory Committee, and the National Advisory Board for the Boy Scouts of America and its Information Delivery Committee, and the Board of HCJB Global. He is a frequent speaker at universities, companies, technical workshops, and conferences around the globe. Professor Roberson has BS degrees in Electrical Engineering and in Physics from Washington State University and a MSEE degree from Stanford.

Kenneth J. Zdunek, Ph.D. –V.P. and Chief Technology Officer

Dr. Zdunek is Vice President and the Chief Technology Officer of Roberson and Associates. He has 35 years of experience in wireless communications and public safety systems. Concurrently he is a research faculty member in Electrical Engineering at the Illinois Institute of Technology, in Chicago, Illinois, where he conducts research in the area of dynamic spectrum access and efficient spectrum utilization, and teaches a graduate course in wireless communication system design. He is a Fellow of the IEEE, recognized for his leadership in integrating voice and data in wireless networks. Prior to joining Roberson and Associates, he was VP of Networks Research at Motorola, a position he held for 9 years. Dr. Zdunek was awarded Motorola's patent of the year award in 2002 for a voice-data integration approach that is licensed and extensively used in GSM GPRS. He holds 17 other patents, included patents used in public safety trunked systems and cellular and trunked systems roaming. He directed the invention and validation of Nextel's iDEN™ voice-data air interface and IP based roaming approach, and was the principal architect of Motorola's SmartNet™ public safety trunking protocol suite. In the 1990's, he directed a Spectrum Utilization and Public Safety Spectrum Needs Projection submitted to the FEDERAL COMMUNICATIONS COMMISSION in support of the 700 MHz spectrum allocation for Public Safety. He was awarded the BSEE and MSEE degrees from Northwestern University, and the Ph.D. EE degree from the Illinois Institute of Technology. He is a registered Professional Engineer in the State of Illinois. He is past president, and on the board of directors of the Chicago Public Schools Student Science Fair, Inc.

Roger Peterson, Ph.D., Senior Principal Investigator

Roger Peterson is a Lifetime Fellow of the IEEE and co-author of four text books on digital communications and spread spectrum technology. He has more than 30 years of experience in digital communications technology and has served as associate editor for spread spectrum for the *IEEE Transactions on Communications*. Prior to joining Roberson and Associates he was a Fellow of the Technical Staff at Motorola Labs where, most recently, he was responsible for system-level capacity analysis of relay-assisted WiMax systems. He is the author of numerous technical papers and holds six issued US patents. He received the BS, MS, and PhD degrees in electrical engineering from the Illinois Institute of Technology.

Alan Wilson, Principal Engineer III

Mr. Wilson joined Roberson and Associates in 2016 and has 40 years' experience in the Telecommunications industry. Mr. Wilson worked at Motorola to develop the Astro product line that supports the Project 25 radio standards suite. This became a $6 billion business for Motorola that has continued to diversify beyond the original market for public safety and mission-critical radios. Mr. Wilson authored dozens of standards for the P25 standards suite that were published by the Telecommunications Industry Association (TIA). He moved to Tyco Electronics and later Harris Corporation to continue to work on P25 standards for Phase 2 to double the spectrum efficiency with Time Division Multiplexing Access (TDMA). After the launch of Phase 2, Mr. Wilson chaired the wide band data committee to begin working on the Mission Critical Push to Talk (PTT) standards for 3G PTT and Long Term Evolution (LTE) through a joint project with Alliance of Telecommunications Industry Solutions (ATIS). The joint project is known as Joint Land Mobile Radio Long Term Evolution (JLMRLTE), and it intends to interconnect private Land Mobile Radio (LMR) radio systems with LTE telephone systems to provide encrypted digital voice and data services across networks. Mr. Wilson has been an inventor on 27 patents and an author of several publications by the Telecommunications Industry Association (TIA) and Project 25 Technology Interest Group. Mr. Wilson earned his Bachelor of Science in Electrical Engineering from

Massachusetts Institute of Technology a Master of Science in Electrical Engineering from Illinois Institute of Technology.